



How does Absorptive Capacity develop in Small-Medium-sized Enterprises (SMEs)?

*The role of absorptive capacity, collaboration and innovation between
SMEs and a regional university.*

A thesis submitted in fulfilment of the requirements for the degree
of Master of Social Science

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August 2018

DECLARATION

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed. I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

15th August 2018

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ABSTRACT

The study examines how Small-Medium-sized Enterprises (SMEs) demonstrate a range of innovation capabilities when they collaborate with a regional university research centre. This collaboration is shown to be important to create and exchange new knowledge to advance the firms innovation performance. The study demonstrates the ability of firms to acquire and exploit this knowledge, which is a business competency described as absorptive capacity (AC). AC relies on several antecedents or factors to engage with a collective learning process. Collective learning is synonymous with collaboration, and from hereon is referred to as 'collaborative learning', as defined by Salk and Simonin (2011). It refers to the joint action to make sense of new knowledge in a purposeful relationship such as strategic alliances and partnerships. This involves the identification, transfer, and experimentation with knowledge originating with another entity. It has the potential to enhance an existing firm's competency or create new competences within a firm (Salk and Simonin, in Easterby-Smith and Lyles (2011, p. 606)).

This work is framed by key theories that discuss the contribution and role of knowledge and innovation to regional economic development, including the nature and types of industry and university collaborations. Common types of collaborations include selective alliances and partnerships to create and exchange new knowledge. Such arrangements between firms and universities can be invaluable to industry where it can apply and exploit the new knowledge to its business environment. The thesis identifies how SMEs AC is developed through collaboration as influenced by several antecedents (Lane, Koka, & Pathak, 2006; Volberda, Foss, & Lyles, 2010). One AC antecedent or factor that trigger a firm's innovation capabilities includes inter-organisational relationships with external partners. Inter-organisational cooperation occurs in many forms, motivated by associated benefits of joint parties involved in collaborative learning. Other determinants include intra-organisational, prior knowledge, business management and environmental conditions (Volberda et al., 2010).

Collaborative learning and partnering is important for SMEs to overcome constraints to innovation activity attributed by limited financial and human capital. Having developed new knowledge with a university, such as a novel idea or prototype invention, a firm can explore ways its business can exploit this novelty to its market place. The study focuses on product innovations developed through phases of the New Product Development (NPD) process as outlined by Buganza, Colombo, and Landoni (2014). Product innovation performance has been recognised as a means of business renewal if firms are to survive and prosper in dynamic economic settings, characterised by fast changes in customers, technologies and competition (Danneels, 2002, p. 1095).

The project adopts a qualitative case study research methodology to show how a small cohort of innovative 'advanced' manufacturing SMEs collaborates with an entrepreneurial university outside an Australian capital city. The thesis demonstrates that a firm with a high level of AC can develop a range of innovation capabilities that contribute to product innovation. These capabilities can improve the competitiveness of SMEs in Australia. The study assists with understanding how innovation competency can create conditions to develop an 'open' innovation system to improve the exchange and flows of new knowledge production between industry-university.

ACKNOWLEDGEMENTS

Having embarked on this research pathway in early 2015 with some reservations and limitations it is great to know persistence has paid off and the thesis is completed. A special thanks to my senior supervisor Professor Bruce Wilson and associate supervisor Dr Nicole Pepperell for their support to get me to this point. The research process has been a rollercoaster ride of highs and lows and it is a precarious journey. I am now enlightened by the experience. I especially like to thank my family, namely my mother, and many friends who shouted me meals and a kind word of support along the way. Here's to new knowledge and research rigour!

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1 CHAPTER ONE: INTRODUCTION

The study examines how Small-Medium-sized Enterprises (SMEs) demonstrate a range of innovation capabilities when they collaborate with a regional university research centre. This collaboration is shown to be important to create and exchange new knowledge to advance the firms innovation performance. The study demonstrates the ability of firms to acquire and exploit this knowledge, which is a business competency described as 'absorptive capacity' (AC). AC relies on several antecedents or factors to engage with collective or joint learning processes associated with collaborative practices. Collective learning is synonymous with collaboration and will be referred to as 'collaborative learning', as defined by Salk and Simonin (2011) from hereon. It refers to the joint action to make sense of new knowledge in a purposeful relationship such as strategic alliances and partnerships. This involves the identification, transfer, and experimentation with knowledge originating with another entity. It has the potential to enhance an existing firm's competency or create new competences within a firm (Salk and Simonin, in Easterby-Smith and Lyles (2011, p. 606)).

This chapter outlines the research background to the study and provides a brief overview of the current literature. This thesis presents a qualitative case study that examines how a group of SMEs collaborates (through formal and informal strategic alliances and partnerships) with a regional university as a source of external new knowledge (Ankrah & Al-Tabbaa, 2015). The Oslo Manual (OECD & Communities, 2005) states there are two main options for a firm to improve its products, capabilities or production, marketing and organisational systems: (i) it can invest in creative activities to develop innovations in house, either alone or in conjunction with external partners; or (ii) it can adopt innovations developed by other firms or institutions as part of a diffusion process.

These two options offer countless combinations. A firm may adopt an organisational innovation developed by another firm and adjusts it to function with its own work routines, or adapts new manufacturing technology to its production line, or when it introduces a new component obtained from a supplier into a consumer product. Both the creation and adoption of innovations can involve either intensive learning or interaction with other actors, or minimal external linkages. A firm can innovate through a range of R&D and non-R&D activities.¹ All these innovation activities have as

¹ R&D is defined by the Frascati Manual (OECD, 2002) to include:

i) The firm can engage in basic and applied research to acquire new knowledge and direct research towards specific inventions or modifications of existing techniques.

ii) It can develop new product or process concepts or other new methods to assess whether they are feasible and viable, a stage which may involve: a) development and testing; and b) further research to modify designs or technical functions.

A firm can engage in many non-R&D activities that can be part of innovation. These activities can strengthen capabilities that enable the development of innovations or the ability to successfully adopt innovations developed by other firms or institutions:

iii) It can identify new concepts for products, processes, marketing methods or organisational changes:

a) via its marketing side and relations with users;

b) via the identification of opportunities for commercialisation resulting from its own or others' basic or strategic research;

c) via its design and development capabilities;

d) by monitoring competitors; and

their end objective the improvement of the firm's performance. They can be intended to develop and implement new products and processes, new methods of promoting and selling the firm's products and/or changes in the firm's organisational internal practices and structure.

This study examines how some of these combinations manifest in collaborative relationships between selected SMEs and Deakin University. Deakin University is a young entrepreneurial higher educational institution that opened in 1978 at Waurn Ponds in the Greater Geelong region (see figure 1). The University was the first regional university in Victoria and later established a campus in the city centre of Geelong and a campus in the Melbourne suburb of Burwood. Geelong City is located some 80 kilometres south-west of Melbourne's central business district. It is a regional city with an urban population of over 235,000 people that provides a wide range of facilities and services to another 170,000 in the wider south-west region of Victoria. This includes the smaller town of Warrnambool and many rural towns and communities.

The firms in this study have emerged from an industry base connected to Deakin's research focus on advanced technological commercial applications of light-weight and composite materials such as carbon fibres, polymers, composite materials and textiles. Deakin's research into fibres, polymers, composites and textiles is based at the Institute for Frontier Materials (IFM). The IFM is responsible for forging new developments into novel and promising technology with a range of commercial applications with its industry partners. The firms selected for the research case study have all sourced knowledge from the University as part of its innovation strategy. They have contributed funds towards specific R&D projects under the auspicious of the Australian Research Council (ARC) Industrial Transformation Research Program (ITRP). This funding created the Futures Fibre Hub (FFH) at the University's Waurn Ponds Campus in Geelong.

Through a qualitative case study methodology, this research seeks to identify, explore and understand industry-university innovation collaborations for SMEs. From a firm's perspective, this involves understanding the nature and extent to which SMEs engage with universities as an external knowledge source. This research has identified specific routines and practices that can be evaluated using the theoretical construct of AC, which broadly is designed to capture a firm's capabilities to innovate. The study answers a call to develop a greater understanding of the AC concept – specifically from a qualitative perspective due to criticisms of quantitative approaches given by Lane, Koka, and Pathak (2006). The work of Jones and Craven (2001), Jones (2006), and Easterby-Smith,

e) by using consultants.

iv) It can buy technical information, paying fees or royalties for patented inventions (which usually require research and development work to adapt and modify the invention to its own needs), or buy 'know-how' and skills through engineering, design or other consultancy services.

v) Human skills can be developed (through internal training) or purchased (by hiring); tacit and informal learning – "learning by doing" – may also be involved.

vi) It can invest in equipment, software or intermediate inputs that embody the innovative work of others.

vii) It can reorganise management systems and its overall business activities.

viii) It can develop new methods of marketing and selling its goods and services.

Lyles, and Tsang (2008) are examples of qualitative studies of AC. Criticisms of AC studies that adopt a quantitative method gives opportunities for further qualitative research work in this field. Qualitative research methods can adopt a practice-based approach in in line with Cook and Brown (1999) as discussed by Duchek, (2013, p.322). Considering such criticisms, there have been more recent attempts and advances to derive a more valid approach that captures the multi-dimension nature of the AC concept, including Flatten, Engelen, Zahra and Brettel, 2011(a), Gebauer, 2011, and Gebauer, Worch, and Truffer, 2012. The current research contributes to this developing area of qualitative case study method in line with Henry and Foss (2015) and Cunningham, Menter, and Young (2017) as discussed in chapter three.

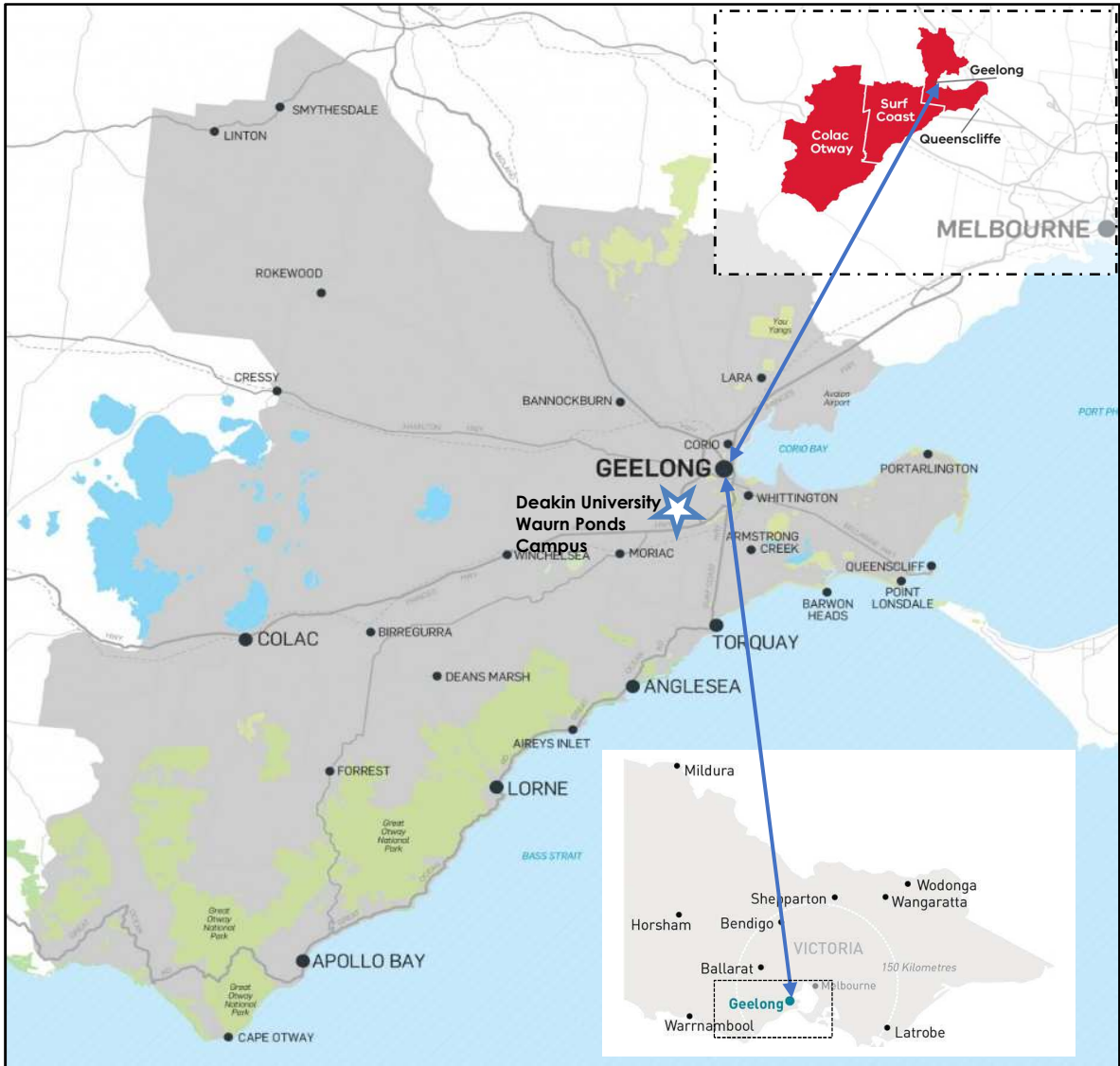


Figure 1: The Greater Geelong and outer SW Victoria Region

The use of in-depth qualitative case studies is recommended to complement the limitations of quantitative macro-economic approaches to the study of knowledge and innovation concepts, particularly at the firm level. Detailed case studies provide a mechanism to examine how external knowledge is acquired by firms and how exactly firms innovate by combining different knowledge bases where quantitative studies fail (Grillitsch, Martin and Srholec, 2017, p.476). The study provides a pragmatic voice to specific experiences of these firms by the methodological decision to focus on

qualitative interviews, supplemented by a single in-depth single case study. To explore this question, this study researched a small group of SMEs that collaborated with Deakin University on a range of R&D projects. Three of the firms are small businesses with fewer than 20 employees; the remaining two are medium sized enterprises with less than 200 employees. The firms range from five years of age to over twenty years in age. Five SMEs participated in the research project to form four separate units of analysis in the case study.

One of the smaller firms (the 5th SME) is a consulting electrical & mechanical engineering company that provides a knowledge intensive business service (KIBS) to the second R&D firm. This fifth firm is combined in the second unit analysis, which discusses the support it provided to the second firm's R&D innovation activity. Apart from the first firm and the KIBS, they all have an internal R&D capacity with a wide range of technological capabilities. The firms also employ many scientific, engineering and trade based technical vocational trained staff on the manufacturing plant floor. Most of the firms' employee R&D staff with research skills developed from applied industry research-based PhD qualifications. Taken together, the selected firms represent a diverse cross-section of experienced SMEs involved in this collaborative research setting. This allowed the thesis to explore the different ways in which universities can be an important source of external knowledge.

The study deploys a theoretical framework to extend Cohen and Levinthal's (1989 and 1990) view that a firm's innovative capabilities are largely a function of its prior related knowledge (Cohen and Levinthal, 1990, p.128). SMEs acquire knowledge from various external sources as part of its network, including customers, suppliers, consultants or KIBS, governments, industry associations, and places of R&D, such as universities. Such sources can contribute to varying degrees of influence to the success of the firm and its innovation performance. Prior research suggests the relative importance of different knowledge sources to industry, can depend on a wide range of factors, including the size of the business, its internal R&D capacity, the industry sector and its level of technology and capabilities and business innovation strategy (Flor, Cooper, and Oltra (2018), (Flor & Oltra, 2013), Rodriguez, Doloreux, and Shearmur (2017); and Pierre and Fernandez (2018)).

The current study focuses particularly on the role played by knowledge and organisational learning, and therefore draws on both the 'knowledge-based view' (KBV) of the firm (Kogut and Zander 1992, 2003; Levinthal and March 1993, Grant, 1996) and the 'innovation system' perspective (Lundvall, et al., 2002, Lundvall, 2007) to frame the literature and theoretical outlook. The KBV of the firm (Kogut and Zander, 1992) considers knowledge stocks to be the most important resource of the firm and the main determinant of economic competitive advantage. This view strongly influences the relevance of the AC construct because it is the key to developing and increasing a firm's knowledge base. AC involves learning processes and interactions between individuals, groups, and organisations (Martinkenaite & Breunig, 2016). Individuals are involved with knowledge sharing and recognition; whilst at the organisational level, routines, histories and stories, documentation, procedures, heuristics, and know-how are important in creating shared understandings of the

knowledge at the firm level (Grant, 1996, Matusik and Heeley 2005). The distribution and flow of different knowledge stocks are also important elements that are related to the recognition, assimilation, and utilisation of new knowledge (Foss, 2006).

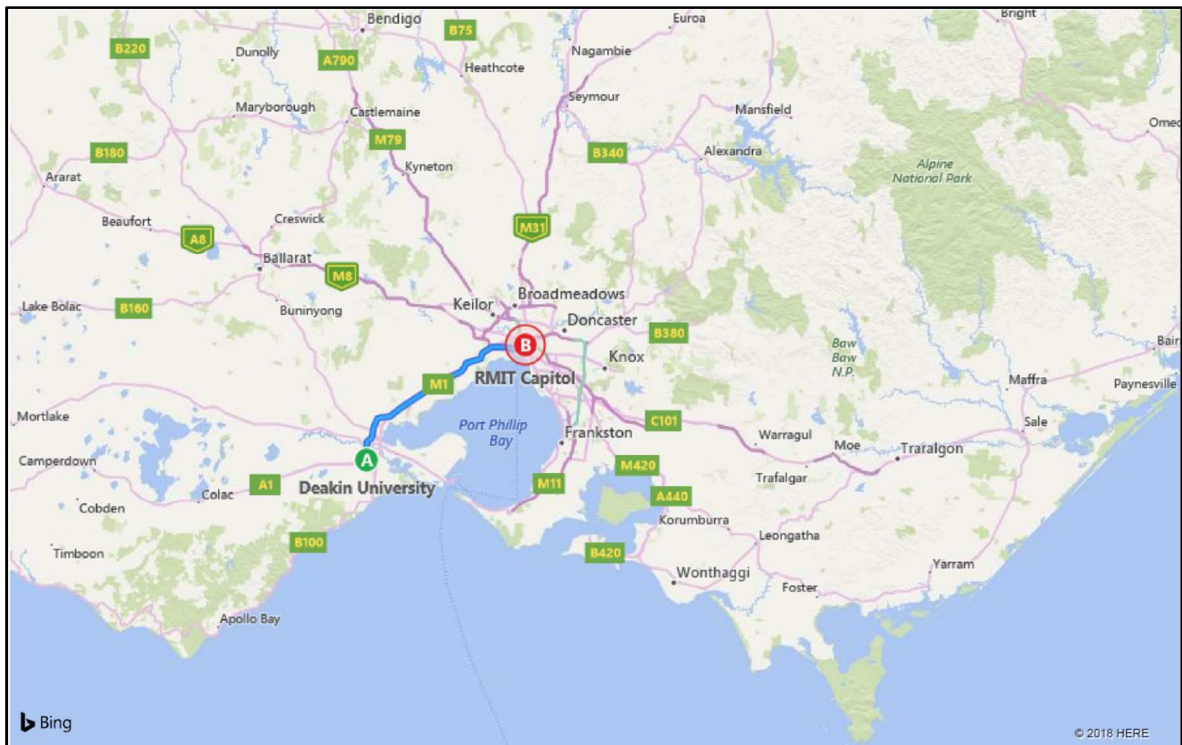


Figure 2: Regional location to Deakin University: Greater Geelong - SW Victoria regions

AC is the quality which enables external knowledge sources to be converted into commercial value through new products, services or processes to support innovation (Cepeda-Carrion, Cegarra-Navarro and Jimenez-Jimenez, 2012, p.110). It has been shown that a firm's innovation performance and outcomes are enhanced when SMEs collaborate with R&D centres, such as universities (Corral de Zubielqui, et al., 2016), specifically in the form of incremental or radical product innovations achieved through the NPD process. Firms with an adequate degree of AC can internalise knowledge acquired from external partners. This knowledge, achieved from strategic alliances, can increase opportunities for product innovations. Such benefits to the firm may be affected by the extent to which a firm's AC is derived from its existing technological knowledge base. Conversely, it is an inability to identify and understand the technological knowledge that underpins partners' competencies limits a firms' collaborative learning potential. (Tsai, 2009, pp. 767-768).

Product innovation performance results from successful commercial applications of new knowledge (Amabile, et al., 1996). Innovation involves two dimensions: technical and non-technical processes that comprise technical design, R&D, manufacturing, management, and the commercial activities that comprise the marketing of a new (or improved) product. The effect on a firm's product innovation performance when collaborating with a network of external knowledge source relies on a firm's AC (Curado, Muñoz-Pascual, and Galende, 2018, p.3). Shin, Kim, and Park (2016) conducted an empirical analysis of the impacts of different types of strategic alliance partners on technological innovation performance within the bio-technology industry. They identify the moderating effect of AC

and potential competition of strategic alliances for R&D activities across three types: vertical-downstream alliances, vertical-upstream alliances (universities, research centres), and horizontal alliances. The results of their study show that an increase in the R&D intensity of a biotechnology firm increases its AC, stimulating the transfer of scientific knowledge or basic technology from research organisations and providing a way to overcome learning difficulties. It shows that biotechnology firms with high AC have higher technological innovation performance than those with low AC.

Najafi-Tavani, et al., (2018) found that the effects of collaborative networks on either product or process innovation capability are significant only in the presence of AC. This suggests that the level of collaboration with different partners can enhance firms' innovation capabilities when firms develop the capabilities to scan and acquire external knowledge. Furthermore, only in the presence of AC, those collaborations with research organisations and competitors have a positive effect on product innovation capability. In the case of process innovation capability, collaboration with research organisations and suppliers are the most important factors (Najafi-Tavani, et al., 2018). Such empirical studies suggest that, while there is some support for collaborating with different partners in product innovations, there is an absence of consensus on the benefits of this type of networking. While collaborating with research organisations, firms with a high level of AC are better able to learn new perspectives, which may provide better, more effective solutions in NPD management processes development. In contrast, an organisation that lacks sufficient AC may be unable to digest advanced technologies when closely collaborating with research organisations (Tsai, 2009, p. 767). The way in which AC affects the relationship between collaboration and product innovation, however, remains in need of further study.

1.1 Research Problem and Propositions

The research problem examines how SMEs develop their AC, which can be an invaluable business capacity that can enhance a firm's innovation performance. It can also serve as to address economic disadvantages associated with firms located in less urbanised regions, such as peripheral regions outside metropolitan capital cities. The limited research and understanding to how SMEs develop AC is the core problem to be addressed in context of a region outside a large metropolitan capital city. AC is seen as an effective business capacity to a firm's strategic innovation to overcome typical barriers SMEs face to sustain a competitive advantage, particularly in a global market. SMEs in peripheral regions do not benefit from the advantages of 'economies of agglomerations' and the effects of '*knowledge spillovers*' (Varga and Schalk, 2004; Grillitsch and Nilsson, 2017; and Vonnahme and Lang, 2017) which are often attributed to larger denser urban regions (Nuur and Laestadius, 2010, p.303).

Typical barriers to innovation for SMEs include reduced organisational resources, structure, and size such as limited financial and human capital to access 'in-house' R&D and/or to harness external knowledge sources, such as universities. To compensate for these limitations SMEs can develop collaborative learning networks with external sources of knowledge (Muscio 2007, p.653; Moilanen, Østbye, and Woll, 2014; Grillitsch and Nilsson, 2015 and 2017). However, a problem exists as businesses in general, and specifically those in Australia, including SMEs, have notoriously low rates of collaboration – particularly with universities, when compared to other OECD countries. Business collaboration on innovation is generally low in Australia. Across a range of collaboration metrics, Australia typically sits in the bottom half of the OECD (Australian Innovation System Report, 2017, p.6).

Australia ranks low on most OECD collaboration measures. Using the broadest scope of collaboration activity, which includes collaboration for purposes other than innovation, it is estimated that 86.3 percent of Australia's innovation-active businesses undertook no collaboration at all in 2015–16. In terms of business-business collaboration on product and process innovation, Australia ranks 25th out of 32 OECD countries, with less than one in four innovative firms collaborating.

The ranking is lower still (26th) in terms of collaboration between innovative firms and their suppliers. In terms of R&D-active firms as a proportion of innovation active businesses, Australia ranks 27th of 27 OECD+ countries, with around one fifth of firms engaging in collaboration.

This suggests the majority of R&D activities are in-house, not involving partnership with other organisations. In 2012-14 (latest internationally comparable data), Australia ranked last of 29 OECD countries for the proportion of SMEs collaborating with universities or other non-commercial research organisations. Large Australian firms performed better, ranking 27th out of 29 OECD countries. (Australian Innovation System Report, 2017, p.16)

This issue has prevailed for a number of years and it has been reported by the Australian Government since 2011. In 2011 the Australian Innovation Systems report concluded that the most prevalent mode of innovation in Australia was the adoption and modification of existing innovations, and that poor networking and collaboration was perhaps the most significant weakness in the Australian Innovation System. The 2012 report described the connection between innovation and productivity growth. It specifically highlighted the role of intangible capital and identified Australia as a 'fast follower' country with regard to adopting and using new knowledge. It noted the comparatively low rates of collaboration; insufficient management capability and a comparably weak innovation culture were suggested as possible factors contributing to the slowdown in Australia's measured productivity growth.

Some of the explanations to the performance of business innovation in Australia include framework conditions refer to as the institutional environment and general conditions for innovation activities, networks and collaboration. These conditions comprise the practices, rules and conventions that collectively regulate the behaviour of actors in the system and encourage or discourage innovation activity. Examples of framework conditions include the tax treatment of research and development (R&D), trade tariffs and industry technology standards, entrepreneurship culture, and attitudes towards risk (Australian Innovation System Report, 2016, p.9).

Despite various identified barriers and disadvantage, SMEs can develop their AC to explore and exploit new knowledge from external networks even across large distances, to sustain innovation activity and competitive advantage. Of those SMEs that do collaborate with universities, the success of introducing new product innovations (goods and/or services) to the market is strong. They become recognised as 'innovation leaders' and can provide an exemplary model to other SMEs. Specifically, such SMEs develop their AC by a range of innovation capabilities. Previous studies of industry-university collaborations place a focus on the business commercialisation phases of knowledge exploration and exploitation. A firm's ability to engage in collaborative learning when knowledge is sourced from a university is important.

This relational capability is critical to the interests of both the firms and the joint interests of partnering organisations, motivated to seek new knowledge to replenish stocks of public and private knowledge, promote innovation activity, and assist economic development (Ankrah and Al-Tabbaa, 2015). Furthermore, there are many economic reasons that make innovation an imperative for businesses. Innovation allows businesses to sustain competitive advantage over their rivals and deal with turbulent business environments generated by fluctuating market conditions and a constant need to embrace and apply new knowledge and technologies. Innovation is understood as knowledge converted into outcomes such as new products, processes or services – or significant changes in the existing ones – for commercial gain and added value.

New product developments are considered as a specific type of innovation. Previous research has identified several factors that directly influence NPD. These include effective internal firm communication, product characteristics, and labour organisation (S. L. Brown & Eisenhardt, 1995). Specifically, evidence of association between AC and NPD can be a good indicator of innovation (Yigitcanlar et al., 2017, p. 322). Firms that continue to adapt to their business environments relies upon several core organisational competences. A firm's innovation competency relies on a strategic innovation management framework that includes five activities: technological integration, product innovation processes involved with NPD, strategic technology planning, organisational change, and business development (Drejer, 2002).

The overall proposition is that when SMEs, develop its innovation competency, they can overcome 'various barriers contributed to their nature. As SMEs rely more on external sources of knowledge, they must be able to both access knowledge and apply it for commercial gains, particularly where it can provide a competitive edge in the market place and improve productivity.

SMEs that have a high AC demonstrate a wide range of 'dynamic' innovation capabilities. This can increase their innovation competency and performance – such as new product development leading to various product and process innovations. SMEs that engage in research and development projects with research leaders in frontier science and technology ('science-based actors') develop new knowledge interactions with a university and can improve their innovation competency.

Studies into the AC of firms have historically been focused on large firms examining investments into the R&D intensity (amount of funding, number of qualified research staff and/or other highly skilled employees) of businesses. Yet the benefits to SMEs from collaborating with an external knowledge source, such as a university, are many (Teixeira, Santos and Delgado, 2013, and Bishop, D'Este, and Neely (2011)). The size of SMEs can limit the extent and stock of their financial and human capacity to participate in innovation activities. To reduce such barriers SMEs and improve their innovation success they can develop their AC to engage and manage knowledge creation and exchange processes from external knowledge sources.

There is a small but growing body of literature that examines the characteristics that inform the capabilities of SMEs to use externally generated scientific knowledge from exchanges with universities. Cohen and Levinthal (1990), for example, have argued that a firm's ability to apply university research for its own commercial gain is a function of its investment in R&D. This research area remains, however, under-explored, particularly with reference to SMEs in regional areas. Through the lens of the AC concept, the current study will contribute to our understanding of the innovation capabilities of SMEs located in a less favoured knowledge-based region outside a metropolitan city and explore the factors that influence their ability to engage with R&D collaborations with a university.

1.2 Research Proposal Statement

This research is a qualitative analysis of a firm's dynamism to embrace change, develop innovation capabilities, and deploy them in turbulent economic times of rapid technological changes and economic globalisation. Examining how AC develops within a small group of selected SMEs that enables innovation through collaboration with an external source of knowledge, such as a university, will assist our understanding and support of regional areas that suffer disadvantages due to geography and weaker systems of innovation support. The research provides insights to how successful firms innovate by examining the factors that make up effective AC. The current literature leaves open which elements of AC prove most useful for understanding how SMEs innovate. Zahra and George (2002), for example, argue for a 'dynamic capabilities' view of AC, which distinguishes between Potential and Realised AC. Grant and Baden-Fuller (2004) suggest that the important capability should be accessing the alliance and co-operating partner's knowledge bases.

Alliances are a means for organisational learning because the motivation of alliances is driven by the desire of firms to obtain knowledge from each other (Apriliyanti and Alon, 2017, p.898). Collaboration between industry and universities has become a topical subject in recent innovation policy discussions regarding Australia's future economic growth and development. Historically, strategic alliances and collaborations have had varying degrees of success and have a high propensity to fail to meet the interests of one or more partners involved. Despite this, there are several benefits that may motivate industry to collaborate with a university. Although there is an established link between

industry-university collaboration and firms' innovativeness, the extent for such cooperation depends on various factors that would benefit from further exploration.

Hagedoorn, Link, and Vonortas (2000) and Hagedoorn (2002) present several motives for firms engaging in inter-organisational R&D partnerships such as broadening the scope of activities, gaining access to investment options, complementary resources and capabilities, and facilitating learning and efficiency. Research identifies firms that pursue R&D partnerships as an open search strategy for external knowledge collaborate more with universities as a specialist knowledge provider (Laursen and Salter, 2004 & 2006; Tether and Tajar, 2008). Firms that actively observe external knowledge are more likely to collaborate with universities while the level of such collaboration is contingent on their network interaction for knowledge generation and their willingness to signal competences (Fontana, Geuna, & Matt, 2006).

This thesis contributes to the 'dynamic capability' view of AC (Shin, et al., 2016) by examining some of the intricacies of AC within context of the exploration and exploitation learning processes of collaborative alliances. Within the context of acquiring and exploiting knowledge, it is also important to understand how the AC of collaborative alliances facilitates adaptations of the learning processes required for adjusting knowledge for economic development and innovation in regional situations. An explicit understanding about the nature of AC in collaborative alliances would both shed further light on the AC and dynamic capability concepts and advance our insights about the role of learning and knowledge production in a regional innovation system (RIS).

The case study presents the story of five SMEs to reveal a deeper understanding of a firm's capacity to innovate by collaborating with a university. A firm with a high level of AC can develop a range of innovation capabilities that contribute to product innovation. These capabilities can improve the competitiveness of SMEs in Australia. The study assists with understanding how innovation competency can create conditions to develop an 'open' innovation system to improve the exchange and flows of new knowledge production between industry and universities. Critical to the advancement of the AC literature is the need to move away from a structural perspective of AC to a view of it as more of a dynamic capability. This perspective focuses attention on the structure, policies, and processes within the organisation that affect knowledge transfer, sharing, integration, and creation. These, in turn, influence the efficiency and the effectiveness of the firm's AC (Lane, et al; 2006, p.857).

1.3 Research Aim and Objectives

The research aims to provide deeper insights of the characteristics to AC of SMEs collaborating with a university. A firm's innovation capacity can be evaluated using a variety of measures (Boly, Morel, Assielou, & Camargo, 2014). AC seeks to measure capacity for innovative activities, which is understood as a core competency needed for businesses to improve their innovation performance and their overall competitive advantage. A 'core competence' can be thought of as a firm's 'knowledge', which enables technical change to set in and innovation to occur, generating sustained

growth (Seddighi, 2015, p. 217). A firm's innovation competency will improve a firm's propensity to engage in NPD and increase commercial applications of new products such as goods and/or services.

The research is also situated within a broader debate over the economic capability and 'dynamism' of a regional locality to use knowledge to support economic development as part of an open RIS. Such initiatives adopt a systematic approach to achieve mutually inclusive goals to integrate economic, business and industry development, with research, science and technological development of a regional territory as part of the overall national economy. Understanding how inventions and new knowledge contribute to commercial innovation by industry and the geographical locations, and patterns of this development is crucial to understanding how regional innovation capacity contributes to regional economic growth and development (Capello, 2013, p. 187).

The research seeks to achieve four driving objectives:

1. To contribute to a new paradigm for the role of a firm's AC in regional economic development literature as an important endogenous element to sustain regional growth and promote economic development.
2. To highlight the relationship between two important participants ['actors' – SMEs and universities] in context of 'a place' and the contribution it can make towards developing the innovation capacity of a RIS.
3. To provide a qualitative methodology for an empirical investigation to a firm's innovation performance through the operation of the AC concept.
4. To examine the role of AC expressed as a firm's competency or proficiency shown by identifiable innovation capabilities in context of its internal capacity to explore and exploit knowledge sourced from a university.

1.4 Research Questions

The ability of SMEs within less favoured areas to be innovative has been subject to limited research, most of which has been conducted in Europe and the UK. General research conclusions state the capacity of firms to engage in external knowledge networks and important sources of science-based research such as a university limits the economic competitive nature of these regions. As such, the research questions are derived from a research inquiry into the effects of AC to a SMEs innovation competency and the development of a firm's innovation capabilities. The research aids further study into the development of a multi-dimensional qualitative story of a firm's innovation capabilities, as derived from its AC, and its contribution to regional development policy and theory. Further research in this regard will contribute to regional development literatures to support a theoretical and methodological framework for the study of SMEs in these locations. Moreover, the research into highly innovative SMEs can further strengthen the case for further studies into innovation capabilities to give a stronger case to provide a 'future proofing' strategy to struggling regions Australia.

The overall key research question is simply stated as:

How do SMEs innovate by collaborating with a regional university?

This research question has vexed many economists and when examined from a micro-economic perspective casts up business economic concepts that have evolved from the behavioural and evolutionary economic streams. These streams attempt to move away from traditional neo-classical economics and the original theory of the firm, as Teece (2017) explains: The theory of the firm has received considerable attention since Ronald Coase's famous 1937 article on 'The Nature of the Firm'. Economists have begun to grapple with questions such as (i) why firms exist in a market economy; (ii) what determines the boundaries of the firm; (iii) how firms should be organized to align incentives for managers and owners; and (iv) how they should be structured financially to maximize profits and minimize managerial malfeasance. Economists have been silent for too long on critical managerial issues such as:

- how firms innovate (beyond just spending money on R&D);
- why firms have capabilities that transcend the sum of individual skills of their employees and contractors;
- how individual firms evolve to build and sustain competitive advantage over rivals.

The broad question harks back to classic research questions as to how 'exploration' and 'exploitation' should be combined (March, 1991). R&D companies must achieve innovative new products through the acquisition of new knowledge and capabilities to ensure growth over the long-term, while at the same time, these companies must also ensure profitability in the short term by raising the level of efficiency and reliability of existing products (Kodama & Shibata, 2014, p.279).

This key question is determined via finding answers to the following sub-questions of interest include:

- 1. How do firms develop innovation competency?**
 - 2. How do firms develop R&D collaborations with a university, as a source of external knowledge to a firm's innovation activity?**
 - 3. Do highly innovative SMEs, which show exemplary innovation capabilities, provide a strategy for struggling regions in Australia?**
-

To provide answers to these questions this thesis analyses interview data collected from a selected purposive sample of staff from five SMEs and Deakin University staff. The research participants are involved in regularly R&D activities and the exchange of knowledge to develop new products. The study focussed on the role of collaborations during a broad three stage NPD process to derive at a firm's product innovation outcomes in the form of new goods and/or services.

1.5 Theoretical Framework

The research's theoretical framework is based on the following order of concepts that relate to a firm's innovation competency:

1. Absorptive Capacity (AC)
2. Nature of Knowledge and Technology Exchanges (Transfers)
3. Dynamic Capability
4. Antecedents of Absorptive Capacity
5. R&D and related non-R&D innovation activities
6. New Product Development (NPD) process for product innovations.

These concepts are elaborated further as discussed in chapter two embraced by the research methodology in chapter three which explains how these concepts have informed the qualitative research design conducted in chapter four and the analysis in chapter five.

1.6 Thesis Overview

Chapter one has set the scene with an overview of the context to the research. The broad research literature relating to the AC construct is outlined with considerations to the business knowledge management, economic geography and regional economic development knowledge bases / domains. The thesis focuses on the second of two broad problems identified:

- (i) The diversity and multi-dimensional aspects of SMEs AC; and
- (ii) The limited knowledge of the AC of SMEs in Peripheral Regions [with a specific focus on the dynamics of knowledge exchanges between industries and universities].

Chapter two provides background information to the research problem, reviews the literature and identifies gaps as they relate to the AC of SMEs. The predominant research is undertaken on larger firms, but increasingly research is examining smaller firm sizes. Consistently, these studies adopt the four dimensions of the Zahra and George (2002) elaboration of the construct that this research also applies. The chapter provides some further insights into the literature and identifies relevant discussion for this thesis.

Chapter three presents the research methodology for the case study that includes: (i) defining and selecting the case/s; (ii) collecting and analysing data; (iii) interpreting data; and (iv) reporting the findings. The research deploys a case study method to analyse the research data collected, along with an explanation of the approach to address the research questions.

Chapter four discusses the case study in detail with reference to participants' responses to the interview questions to provide a story of an embedded small group of SMEs collaborating with Deakin University. SMEs rely on several antecedents that contribute to a firm's AC to innovate successfully and this involves a variety of internal and external organisational dynamic capabilities.

Chapter five will discuss the analysis and findings of the case study data. Specifically, this chapter discusses the literature and raises some further considerations to the theoretical discourse of a firm's AC, especially for SMEs. The collaborations SMEs adopt will vary with the university depending on the different phases of the NPD process; ultimately the successful outcome of collaborations informs the innovation performance and outcomes of each firm.

Chapter six concludes with a summary of the implications of research findings with concluding observational analysis of the firm's explorative and exploitation experiences with product innovation. An implication of this research includes a need for firms to develop its AC, and specifically its innovation capabilities across the NDP process in collaboration with universities.

2 CHAPTER TWO: LITERATURE REVIEW

This chapter reviews the relevant absorptive capacity (AC) literature to show how this concept contributes to a firm's innovation performance. This chapter argues that the literature suggests three major areas in need of further research include: to expand the approaches take to measure and study AC – particularly from a qualitative research method; the relatively limited research into the role of the concept for SMEs and economic development of less favoured or peripheral regional areas; and the nature and role of external knowledge source exchanges between industry and universities. AC literature overlaps with other organisational management theory to create an interdisciplinary and multi-dimensional view of the construct which can create confusion and misgivings to its application (Apriliyanti and Alon, 2017). This characteristic, however, also makes the AC a flexible construct that can be diffused and integrated with other associated theories across organisational learning theory (Apriliyanti and Alon, 2017, p.898).

2.1 Absorptive Capacity: An Overview

A firm's AC is typically assessed by studies adopting quantitative measures applying econometric models using statistical data from commonly designed innovation surveys consistent with the OECD Oslo Manual (2005). Quantitative studies that measure AC in this manner generally infer that a firm's innovation performance is mediated through outcomes such as the number of patents issued; the level of R&D investment (funding); employment of highly qualified skilled staff; and a firm's after-tax profit, revenues and product sales performance data, and the like. Such outcomes are presented as quantifiable measures of a firm's AC; higher the performance outcomes are, higher the firm's AC. Much of the background research takes a predominantly quantitative approach that explores the role of AC and external knowledge sources to a firm's innovation performance. This research is largely influenced by quantitative studies of large firms and advanced technology-based SMEs in the European, North American (USA) and increasingly China.

Such empirical studies are constrained by the availability of standardised and broad-based data such as R&D and patent data, as proxies for innovation. This can mean the literature has a bias towards science-based 'new-to-the-world' changes. In the Australian context, such metrics are rarely applied to scales smaller than the national level, which can obscure important regional differences. Limited pieces of research exist in Australia that examines the role of AC as part of the innovation process, including one qualitative case study of firms (Scott-Kemmis, et al., 2007) and a second large scale quantitative study (De Rassenfosse and Webster, 2013). Recently, Corral de Zbielqui, Jones and Lester (2016) have investigated of the significance of scientific research for the innovation performance of SMEs in South Australia.

The current study aims to help redress the limited research on the patterns to innovation performance of Australian SMEs. This research is predominantly in the form of quantitative surveys and econometric statistics. A report to the Australian Government (Arundel, and O'Brien, 2009)

concluded that current survey methods or abilities to measure and obtain information on Australian business innovation performance lacked the following gaps when it comes to indicators for:

- firm-level capabilities, or how firms innovate; and
- indicators for knowledge flows.

AC constitutes a firm's competency developed through learning processes across its internal and external capabilities. AC is a function of an organisation's existing tacit ('know-how') and explicit codified ('know-what' or 'know-do') knowledge, internal routines, organisational learning, management expertise and culture.

Zahra and George (2002) define absorptive concept as a set of organisational routines and processes by which firms acquire, assimilate, transforms and exploit knowledge to produce a dynamic organisational capability. They introduced two stages that scaffold four learning processes:

1. Potential AC stage (or 'exploratory innovation' - learning phase), which encompasses learning processes of AC 1 Acquisition and AC 2 Assimilation of new knowledge; and
2. Realised AC stage (or 'exploitation innovation' - learning phase), which encompasses learning processes of AC 3 Transformation and AC 4 Exploitation of new knowledge.

For a firm to develop and achieve a range of innovation capabilities, it requires to develop knowledge across these four learning dimensions, through what reads as a set of sequential learning steps. They argued that firms need to navigate this process successfully to obtain superior performance.

The current study considers, in part, the applicability of this model to the qualitative data collected from a regional Australian SME perspective. AC is invariably linked to other organisational learning theories and specifically to the concept of dynamic capability (Nelson and Winter, 1982; Teece, Pisano, and Shuen, 1997), emerging beyond the pure resources view of the firm. This implies a distinction between 'capability building' as building upon prior knowledge bases of a firm, rather than merely 'resource-picking'. In order to articulate the capability building mechanism, a distinction between the terms 'resource' and 'capability' is made. Makadok (2001) takes the distinction drawn by Amit and Schoemaker (1993, p. 35). For this research, a firm's innovation competency involves both its potential innovation and realised innovation capacity developed by a range of internal and external capabilities defined by per Lewin, Massini and Peeters, (2011) as discussed further.

Capabilities, refers to a firm's capacity to deploy and use resources, combined with a firm's organisational processes, to affect a desired end. They are information-based, tangible or intangible – processes that are firm-specific and develop over time through complex interactions among the firm's resources. They can abstractly be thought of as 'intermediate goods' generated by the firm to provide enhanced productivity of its resources, as well as strategic flexibility and protection for its final product or service (Makadok, 2001, p. 388). For the purposes of this study, a 'capability' is defined as a special type of 'resource' - specifically, an organisationally embedded, non-transferable firm-specific resource whose purpose is to improve the productivity of the other resources possessed by the firm. Based on this definition, Teece, et al., (1997) have argued that 'capabilities cannot easily

be bought; they must be built.’ Likewise, Amit and Schoemaker (1993, p.35) contend that “*some of the firm’s resources, but especially its capabilities, may be subject to market failure.*” If capabilities must be built, not bought, then a manager’s role may be more nearly analogous to an architect than to a stock-picker trying to beat the market.

The theoretical development of the AC concept originates from organisational learning literature of the 1980s that provided a cognitive (learning) psychological perspective to innovation and economic behaviour and a sociological orientation towards co-evolution of knowledge (Volberda, et al., 2010, p.933). Fiol and Lyles (1985) and Levitt and March (1988) discuss the role of R&D in organisational learning and performance, and Kedia and Bhagat (1988) address the role of organisational characteristics in technology and knowledge transfers. The concept became regarded as a direct outcome of financial investment in traditional R&D activities (Cohen and Levinthal, 1989 and 1990) occurs in large firms and well-funded public universities in the USA, which increasingly worked in collaborative arrangements, laying the foundation, for example, for the early success of Silicon Valley in California, USA. Marabelli and Newell (2014) provides a comprehensive review of AC, including the works of Zahra and George (2002), Lane, et al., (2006), Todorova and Durisin (2007), Easterby-Smith, et al., (2008), Volberda, et al., (2010), Lewin, Massini, and Peeters, (2011) and Gebauer et al., (2012) that are central in this study.

AC is a concept originally defined as a firm’s ability to identify new knowledge from the environment, recognise its value, assimilate it, and exploit it (Cohen and Levinthal, 1989) for commercial purposes. It relies on a firm’s ‘prior knowledge’ (Cohen and Levinthal, 1990) directly developed by investments in R&D capacity particularly by large firms. Consistent with Cohen and Levinthal (1990, p.135), the early work strongly connected learning and innovation processes to the economic performance of firms. This suggested that distinct organisational (intra and inter) mechanisms can influence the level of AC. Such mechanisms included the transfer of knowledge across and within firms, communication structures between the external environment and the firm (i.e. the ‘centralisation of the interface’ function), a broad and active network of internal and external relationships, and cross-function interfaces (Van den Bosch, et al; 1999).

The ‘learning process’, is specifically attributed to the works grounded in the AC concept (Cohen and Levinthal, 1990) and many others known to research in this construct (Tsai, 2001; Muscio, 2007, 2013; and Laperche, 2015). SMEs’ learning process and knowledge management activities play a key role in innovation management (Adams et al., 2006; Darroch, 2005). Several sources of knowledge have been identified (Keskin, 2006, Lee, Tsai, 2005; Nonaka, 1991). The detection and integration of external knowledge increases the knowledge capital of the firm (Darroch, 2005). R&D investments, subcontracting and the integration of networks allow the renewal of internal knowledge (Ferreira et al., 2015). Whatever the source of knowledge, the capacity to absorb it is essential to creating a knowledge-based competitive advantage (Cohen and Levinthal, 1990, Tsai 2001). SMEs usual lack of qualified human resources may have a negative effect on their ability to absorb knowledge (Farace, Mazzotta, 2015; Liu, Laperche, 2015; Muscio, 2007). Pierre and Fernandez (2018, p.164) in their study defined the dimensions to learning processes to include:

1. Knowledge integration: IP thinking; Clear delimitation of knowledge transfer with partners; skilled resources that can integrate external knowledge; and
2. HR training: Internal training on HR specialisation; HR training on diversified knowledge; and Senior profiles integration in training process.

Cohen and Levinthal's argued that the learning potential for AC is determined by prior related knowledge and R&D investments, labelled as the 'cumulateness feature'. Subsequent research examined the AC concept from an organisational context (Lane and Lubatkin 1998, Lane, et al. 2001, Benson and Ziedonis 2009) when knowledge is shared or transferred between firms where the similarity between the firms is more relevant than the R&D. Lane and Lubatkin (1998) coin the term 'relative AC' to describe the phenomenon that firms have various levels of AC and that it is a relative phenomenon. Lane, et al; (2001 and 2006) develops AC as the essential dynamic capability that allows firms to utilise externally held knowledge through three sequential processes:

1. recognising and understanding potentially valuable new knowledge outside the firm through exploratory learning;
2. combining existing knowledge with externally-acquired knowledge through transformative learning; and
3. using the assimilated knowledge to create new knowledge and commercial outputs through exploitative learning (Lane, et al., 2006, p.856).

Their empirical analysis indicated that recognition and assimilation have an impact on the knowledge acquired, and utilisation has a direct positive link to firm performance and innovation outcomes. Lane, et al., (2006) driven by five critical limiting assumptions of AC, concluded the popularity of the construct has led to its reification, which stifles research in this area. They addressed this problem by their own model of AC processes, antecedents, and outcomes. One of the limiting assumptions identified by Lane, et al., (2006) is the lack of research that positions AC squarely as the extension of the resource-based view (RBV) of the firm – namely the 'process-capability' stream of research (Schulze, 1994) – which places less of a premium on acquisition and ownership of resources and more emphasis on the efficient use of resources within the firm (Amit and Schoemaker, 1993; Kogut and Zander, 1992; Nonaka, 1994).

This elaboration of the construct is based on a competitive advantage view of the firm that is seen as a function of how resources – including knowledge – are combined with other resources to develop new competencies and knowledge. A firm's competitive advantage is traditionally viewed in terms of Ricardian rents rather than efficiency rents. They outline alternative views that perceive AC as dependent on processes and routines within the organisation that enable a business to share, communicate, and transfer individual-level learning to the organisational level. It is, thus, path dependent and cumulative. A large majority of studies with a focus on knowledge content have ignored the role of organisational structure in defining the AC of the firm. A much smaller group of studies has adopted the capability approach to AC. Van den Bosch, et al., (1999), is one of the few studies to focus on the overall organisational structure of the firm; they argue that the scope,

flexibility, and efficiency of knowledge assimilation varies, depending on whether the organisation has a functional, divisional, or matrix organisational structure.

“Despite this alignment with the original context of the construct, we believe that equating absorptive capacity with Ricardian rents has significantly limited the development of the field. By focusing on differences between firms’ knowledge content, such studies imply that there is little variation between firms in terms of their processes and, consequently, that processes can be ignored when examining firm performance. However, such an assumption belies the role that processes, and activities play, not just in assimilating and integrating newly acquired knowledge but also in terms of creating new knowledge as a function of combining different resources and capabilities” (Lane, et al., (2006, p.853). Such a capability approach (Lane, et al., 2006, p.847) focuses on both organisational structure and knowledge content as distinctive and integral components of AC, rather than just focused on the “what” of knowledge, which is critical in understanding how organisations acquire, assimilate, and exploit knowledge.

2.2 Innovation, Regional Economic Development and SMEs

Economic geography views regions as spatial units for economic analysis that contribute to an understanding of national economic competitiveness, growth and performance. Porter (1990, 2003) and others raised the discussion and profile of regional economic development competitiveness; in particular a need to examine measures of economic competition and performance beyond that of adopted macro-economic indicators such as GNP and GDP. The role physical location can play to a firm’s competitive advantage has been well established in the literature. This research literature engages with topics about the role of ‘industry clusters’ or ‘industrial districts’, the role of economics of agglomeration, and more recently concepts such as ‘entrepreneurial discovery’ and ‘smart specialisation’. The micro-economic interests pertaining to a firm’s economic competitive performance has also given over to a raft of strategic organisational learning and knowledge management theories that this thesis explores in context of AC and the dynamic capability schools of thought.

Much is said about the role of innovation and economic growth (Ahlstrom, 2010) and in particular the role of the firm to sustain the development of economic competitive regions. The implications of uneven economic growth for some regional areas make the issue very current and topical. SMEs located in regions outside metropolitan locations are not devoid of successful enterprises and industries. Those firms that can adapt and develop agile internal business operations and process will have a higher propensity to be engaged in innovation activities and achieve ongoing competitive economic performance. Insights into the relationship between industrial and economic development and the integration of knowledge creation and innovation theories were framed by Lawson and Lorenz (1999). The concept of firm capabilities or ‘competency’ is embraced by Lawson and Lorenz (1999) to contextualise the development of collaborative among firms at the regional level.

The study's focus on the innovative capabilities of SMEs pertained to an interest to regional economic development theory; namely understanding the welfare of regions and economic disparities between geographical locations. The welfare of such regions and the firms located there has been framed by term a called the 'regional innovation paradox'. The persistence of regional differences in income levels (and employment rates) is explained in part by the regional innovation paradox (Oughton, Landabaso and Morgan, 2002). The low level of R&D does not only hamper the internal innovation activity in the region, it also leads to a low absorption capacity on the part of the regional firms. Therefore, inter-regional knowledge spillovers as well as public innovation funds cannot be absorbed to a sufficient extent in such regions. This is referred as the "regional innovation paradox" (Tödtling and Tripl, 2005).

Thus, funds earmarked for innovation are disproportionately absorbed by richer regions, exacerbating the gap between the richest and poorest regions. The regional innovation paradox refers to the apparent contradiction between the comparatively greater need to spend on innovation in lagging regions and their relatively lower capacity to absorb public funds earmarked for the promotion of innovation and to invest in innovation related activities compared to more advanced regions (Oughton, et al; 2002). SMEs in these regions also suffer economic disadvantages by the larger distances (hence increase transactions costs) from market places, and the lack of critical mass, or clusters, of similar business with supporting supply chains. One of the major economic impacts or disadvantages is a firm's innovation performance or propensity to engage in the innovation process. This requires a firm to access external sources of knowledge and a capacity to adopt a range of innovation activities such as research and development (R&D), which can increase the innovation performance of SMEs (Mitze, Alecke, Reinkowski and Untiedt, 2015, pp. 555-556).

Open Innovation literature has so far witnessed few attempts to explore this subject. Chesbrough and Crowther (2006) for example identified the not-invented-here (NIH) syndrome and lack of internal commitment as main hampering factors. The NIH syndrome has been previously found to be a prominent barrier for external knowledge acquisition (e.g. Katz and Allen, 1982). Although focused on the external acquisition of knowledge, its underlying antecedents are also applicable to technology exploitation, leading to the 'only-used-here' (OUH) syndrome (Lichtenthaler and Ernst, 2006). More potential barriers can again be found in the related literature on collaborative innovation. Boschma (2005) identified various forms of 'proximity' which are essential for effective collaboration. These include cognitive, organisational, cultural and institutional differences between collaboration partners, implying that potential problems may arise due to insufficient knowledge, cultures or modes of organisation, or bureaucratic elements. To mention only a few, other potential barriers include lacking resources, free-riding behaviour, and problems with contracts (Hoffman and Schlosser, 2001; Mohr and Spekman, 1994) in van de Vrande, de Jong, Vanhaverbeke, and de Rochemont, 2009, p.427)).

While proximity perceptions deal with different aspects of inter-firm relations, there is no determinism connected to the theory on proximity saying that actors can share knowledge if they are near each other in the mentioned ways. Proximity describes the relational aspects of firms, but not their internal goals and characteristics. The issue of physical proximity and/or remoteness to metropolitan regions when viewed in terms of accessibility and distance still compromises tacit knowledge diffusion and the role of AC. Recently, the need for cognitive, social, organisation and marketing proximity (Boschma, 2005) are just as relevant or more relevant in a knowledge economy, particularly when dealing with implicit or tacit knowledge. This is due to delays or decay effects of regional knowledge spillovers and the extent and scope of physical interaction and network exchanges between different participants in the modern innovation process.

The ability of SMEs to overcome obstacles attributed by long distances – other than co-location or relocation to places to benefit from economic agglomeration – relies upon increasing capabilities within business and regional locations develop open innovation systems and innovation capabilities to absorb external sources of new knowledge. Firms have different options when it comes to collaborating, and these are grounded in the internal resources of the firm. Teece, et al (1997) sees the goal of the firm as the development of dynamic capabilities. The firm's capability is its 'ability to integrate, build and reconfigure internal and external competences to address rapidly changing environment'. The capability is used for achieving new and innovative forms of competitive advantage. The capability can be enhanced through experience, investment, and new employment (Lorentzen, 2007, pp.15-16).

SMEs propensity to innovate is said to increase due to the role of networks (Gronum, Verreyne and Kastle, 2012), particularly when collaborating (Grillitsch and Nilsson, 2015) with external sources of knowledge, to gain commercial profits from product innovation. Firms that perform better measured in outcomes such as increase sales, net profit, increase market share, product range and market penetration, demonstrate capabilities of high levels of innovation activity. This activity will reflect their capacity to explore and exploit external networks of knowledge and their internal abilities use newly acquired knowledge for product innovation. Another issue that relates to the focus on physical proximity concerns a saturation point or threshold level (Nooteboom, 2000 and 2009, Bloodgood, 2015) by which the size and nature of the external knowledge networks ameliorates the benefits, and this can be related to other proximity dimensions such as cognitive and organisational and others (Boschma, 2005).

Another issue that relates to the focus on physical proximity concerns a saturation point or threshold level by which the 'cognitive distance' (Nooteboom, 2000 and 2009, Bloodgood, 2015) being the size and nature of the external knowledge networks ameliorates the benefits ('crowding effect'), and this can be related to other proximity dimensions such as cognitive and organisational and others (Boschma, 2005). This is the case where networks are very similar, leading to such cognitive barriers as 'group think' mentality and other deficits associated with path dependent social and organisation

norms, routines and values. Molina-Morales, García-Villaverde and Parra-Requena (2014) suggest both a direct and indirect effect of cognitive proximity on a firm's innovation performance. An excess of geographical proximity produces 'spatial lock-in' (path dependency), thus limiting the access to new knowledge and lowering innovations. By contrast, proximity in terms of a firm's goals and culture relating to a territorial cluster can encourage knowledge exchanges and acquiring to generate effective innovations.

Recently the role of regions with a high density of knowledge-based firms, networks and innovative business culture has been reinforced by the OECD document 'The Innovation Imperative: Contributing to Productivity, Growth and Well-Being OECD' (2015). Less favoured regions, where these factors are 'weak or thin' (Tödtling & Trippl, 2005), can result in poor business innovation activity; reduce productivity rates, and impair the capability of traditional low technological industries from adapting to emerging new higher technologies. The problems of uneven economic growth of regional areas have long been a concern in Australia for both economists and policy-makers with a view to creating policies and programs to offset these differences.

Miguélez and Moreno (2013 and 2015), for example, examined the extent to which AC determines knowledge flows impact on regional innovation. They assessed the external inflows of knowledge and information brought in by means of inventor mobility and networks to foster local innovation. They found that inflows of inventors are critical for wealthier regions, while it has more nuanced effects for less developed areas. Their study also showed that regions' AC critically adds a premium to tap into remote knowledge pools conveyed by mobility and networks. To understand how SMEs within a regional location innovate requires consideration of how firms access different sources of external knowledge. One key finding in this broad literature relates to the geography of innovation and the potential innovation capacity of regional actors, such as firms or individuals, to access external knowledge from within and outside their regional location.

Access to continuous flows and stocks of knowledge is essential to business innovation and technological capacity to advance and remain competitive in a global economy. When it comes to accessing external knowledge sources by industry (such as universities) two key patterns have been identified by Moreno and Miguélez, (2013, p.132).

1. Firstly, informal interactions and unintended relations result from spontaneous and chance ('serendipitous') social encounters between firms and an external knowledge source who lie in close spatial proximity to each other.
 - This is often because of informal regular face-to-face interactions between parties to allow for tacit (implicit) knowledge development from collaborative opportunities.
2. Secondly, formal interaction and intended relations develop based on coordinated and well-defined linkages between a firm and an external knowledge source, which might, or might not be in close spatial proximity.

- This involves or embodies codified (explicit) knowledge developed that is easily transmitted following specific formal and costly channels or means.

These two patterns emerge from earlier research undertaken on localisation effects of industry clusters: the role of physical proximity to knowledge creation and the study of uneven distribution of economic and innovation activities across space; as well as the major spatial differences in growth rates between regions, even within the same country (Moreno and Miguélez, 2013, p.133). Therefore, it is proposed that how SMEs innovate in regional locations may broadly depend on these two patterns and the importance of a firm's internal and external AC (Lewin, et al; 2011) to explore and exploit external networks of new knowledge for commercial gain. The role of social networking capabilities to increase the likelihood and impact of knowledge serendipity and knowledge arbitrage events (happy accidents) (Carayannis 2008a, b; Carayannis and Clark 2011 in Carayannis, and Rakhmatullin (2014)) is a pillar of regional economic strategies in European Smart Specialisation Strategies. These 'happy accidents' would then act as triggers, catalysts and accelerators of exploration and exploitation dynamics that could substantially empower any Quadruple Helix RIS3 strategy (see Carayannis 2008a, b in Carayannis, and Rakhmatullin (2014, pp.220-221)).

2.3 Barriers to SMEs Innovation in Peripheral Regions

Peripheral regions, along with the role of innovation, knowledge and entrepreneurial activity have been discussed in regional economic development and growth theories since the early 1950s by well-known economic geographers. Since this period the study of economic geography (the geography of economics) has emerged with clear evidence that the influence and role of 'centrality' and the spread of different sized human settlements (urban centres) provides compelling factors which can create socio-economic disadvantage. Poor accessibility and distances between places (centres) of different population sizes can create economic inequities because of limited knowledge flows, knowledge diffusion and knowledge recombination. Location and size of human settlement is attributed to proximity (distance) from external market places, and access to various business activities and functions associated with the production and trade of products. Many geography innovation scholars have reiterated that the role of physical proximity in enhancing knowledge creation is critical to understand the uneven distribution of economic and innovation activities across space, as well as the major spatial differences in growth rates between regions, even within the same country (Moreno and Miguélez, 2013, p.133).

Peripheral, fringe, and remote human settlements can suffer a range of structural barriers that can limit the stimulation of innovation and entrepreneurship of smaller businesses. Of interest is the role of knowledge, specifically its knowledge 'spillover effects' by the creation and exchange of new knowledge from external sources to the innovation production process and generation of business activity, in terms of new firm creations and industries, specifically SMEs, as an important source of economic growth. The production of innovation relies on the recombination of existing knowledge,

information and ideas. The role of geography, particularly spatial proximity, does matter when it comes to the economics of innovation, knowledge production function and technological change.

Redefining a methodology in the 21st century for small business innovation to drive economic development in peripheral, sparsely populated regions, needs to take account for less codified forms (tacit) knowledge that is 'sticky' and more difficult to transfer as part of the knowledge exchange stage between economic agents (participants) of the innovation process. These are harder to measure quantitatively and are not reflected in macro-economic data such as government and business R&D expenditure or use of company Intellectual Property (IP) information such as patent data. These innovation measures reflect older linear innovation models, economies based on older manufacturing processes and do not account for many broader aspects of innovation like human capacity such as innovation capabilities and diverse highly skilled labour pools (Davis, Michie and Vironen, in De Souza and Dawson (Eds), 2012, pp.120-121) which can only be assessed and measured through qualitative methods.

The capacity of SMEs to do business, remain competitive and survive is a grand challenge in and of itself. As such the refinement of existing business products with rapidly changing technology needs to be matched by the firm's innovation performance and the innovation activities it engages with. SMEs in general can be plagued by several barriers and obstacles to engage with the innovation process (North and Smallbone, 2000a, 2000b, Gray, 2006, and van de Vrande, de Jong, Vanhaverbeke, and de Rochemont, 2009). These barriers and obstacles are exacerbated within peripheral regions have been discussed by various people such as McAdam, McConvery and Armstrong (2004); Harris, McAdam, McCausland and Reid (2013a); Harris, McAdam, McCausland and Reid (2013b); McAdam, Reid and Shevlin (2014).

SMEs located in non-metropolitan regions or peripheral regions are said to suffer many barriers and obstacles to explore and exploit knowledge to achieve commercial gain from new or modified product development. The term 'non-core' region was introduced by Lagendijk and Lorentzen (2007) and refers to regions located 'outside the principal metropolitan areas' Here, the differentiation between 'core' and 'non-core' regions is used since other common dichotomies do not cover all the regions (Paasi, 1996, p. 208 in Lagendijk and Lorentzen, 2007, p.459). The interest in the innovative capabilities of non-metropolitan SMEs firms pertains to a central interest to regional economic development theory – understanding the welfare of regions and economic disparities between places.

More potential barriers to SMEs in peripheral regions can again be found in the related literature on regional economic development and innovation systems. Other challenges – such as physical proximity viewed in terms of the distance, time and cost it takes to travel due to poor transportation networks – and financial and human capacity deficiencies can impede business growth and the contribution that regions make to local economic development. Advances in Information Communication and Technology (ICT) has reduced the need for physical proximity to metropolitan

city centres in terms of transfer of basic codified knowledge and communications, however, more intricate tacit knowledge exchanges required other dimensions to learning. Despite the benefits of ICT, modern global markets and the complex nature of knowledge has meant other proximity dimensions are equally as important in the 21st century.

The process of producing, marketing and trading of new goods and services is occurring at increasingly faster rates. This can generate higher exchanges of capital and cash flows into and out of the economy and the market place. The ability for business to engage in trade; to sell goods and services and generate commercial value is essential for business creation, growth and survival. Innovation plays a contributing role to business ability to remain competitive and productive in the market place. Beyond location, proximity to markets and population size, other endogenous factors have been considered which added to original external (exogenous) view of regions. Regional economic development theories today form integrated hybrids of traditional exogenous models and endogenous considerations, particularly the value to creating and accessing external new knowledge (knowledge spillovers), and the ability of regional production systems to engage with the innovation process.

Economic agents engaged in the innovation process do not produce innovations in isolation; this relies on the recombination of existing knowledge and ideas often through industry-university collaborations, involving scientific R&D to create new knowledge and technology advancements. Firms and the staff they employ create and recombine ideas through collaborative processes structured within the organisation (March; 1991; Lorenz; 1996) *"In short, firms turn to external sources of ideas and their ability to recombine and exploit such knowledge is pivotal to boost their competitive advantage"* (Moreno and Miguélez, in McCann and Oxley (Eds), 2013, p.131). Organisations that produce innovations by combining existing knowledge that goes beyond the limits of their boundaries and regional location can capture access to *'extra-regional innovation'* in addition to local socio-economic filter conditions (Crescenzi and Rodríguez-Pose, in McCann and Oxley, 2013, p.163). Cassiman and Veugelers (2006), amongst others, have consistently shown that complementarities between firms' internal R&D activities and their external knowledge acquisition are strong predictors of performance.

Firms have different options when it comes to collaboration, and these are grounded in the internal resources of the firm. Teece, Pisano and Shuen (1997) see the goal of the firm as the development of dynamic capabilities. The firm's capability is its 'ability to integrate, build and reconfigure internal and external competences to address rapidly changing environment'. The capability is used for achieving new and innovative forms of competitive advantage. The capability can be enhanced through experience, investment, and new employment (Lorentzen, 2007, pp.15-16). The issue of physical proximity and/or remoteness to metropolitan regions when viewed in terms of accessibility and distance still compromises tacit knowledge diffusion and the role of absorptive capacity.

2.4 Absorptive Capacity and Dynamic Capability

Early conceptualisations of AC focused on R&D issues, later research broadened the concept to developing AC at the organisational level (Lichtenthaler, 2009). Much of the existing research describes AC as an independent variable and innovation performance as the dependent variable or moderated by a firm's AC. In the case of smaller firms, however, the focus on developing AC is more commonly related to a non-linear view of the innovation process (Aribi and Dupouët, 2016), where SMEs with less R&D investment activity manage to develop AC using collaborative networks of different external knowledge sources. AC becomes a dynamic capacity when these innovation capabilities engages successfully across the relevant AC phases and enacts the three major tenets of dynamic capability theory.

Zahra and George (2002) placed AC in the context of its complementary use with “dynamic capability concept (Teece and Pisano, 1994; and Teece, et al; 1997). The concept of dynamic capabilities comes from evolutionary economics theory of the firm (Nelson and Winter, 1982) which emerged within the knowledge economy movement of the last two or more decades. The concept of AC as a dynamic capability can be simply expressed by comparing the four essential tenets of dynamic capability found in Teece, Pisano, and Shuen (1997) *build, reconfigure, integrate and replicate/imitate*) with that of four dimensions to AC of Zahra and George (2002) *acquire, assimilate, transform and exploit* (see, for example, Noblet, Simon, and Parent (2015) and Denford, 2013).

Dynamic capability is a ‘meta-competence’ that transcends operational competence associated with business-as-usual ordinary routines. It enables firms, not just to invent, but also to innovate profitably (Teece, 1986, 2006). Winter (2003) defines dynamic capabilities as ‘high level routine(s)’ which in turn are ‘learned and repetitious behaviours’ (Winter, 2003, p. 991). Dynamic capability refers to the generation of knowledge concerning the methods that can be used to improve the existing competency of the firm and/or to develop new capabilities. There are three central aspects to dynamic capabilities of a firm:

1. Sharing knowledge among members of the organisation; knowledge tends to be tacit embodied in firm routines and procedures, to encourage collaborative learning.
2. Combining diverse knowledge to generate new knowledge within the firm.
3. Adapting established procedures and routine which embodies knowledge to make effective use of new knowledge and prevent organisation inertia and resistance to change.

Winter (2003 and 2013) proposes the view of learning as a deliberate action and habit-forming process. It is ultimately a second or ‘higher’ order capability over and above routine daily operational first order business capabilities. This view creates an explicit link between the concepts of organisational learning and dynamic capabilities. This hierarchical classification has increasingly been adopted in recent models of dynamic capabilities (e.g. Helfat and Peteraf, 2003; Zahra and George, 2002; Zahra, Sapienza, and Davidsson, 2006) and helps to eliminate the tautological flavour associated with dynamic capabilities. In addition, Teece (2007, p.1319) establishes an explicit

connection between dynamic capabilities and knowledge management, when he proposes that 'dynamic capabilities can be disaggregated into the capacity

- (i) to sense and shape opportunities and threats,
- (ii) to seize opportunities, and
- (iii) to maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets,' and includes knowledge management as part of the third type of process (Vera, Crossan, and Apaydin, p.159 in Easterby-Smith, et al., 2011).

Teece (2010, 2007) and Teece, et al., (1997) distinguish ordinary – or 'substantive' lower order operational capabilities from that of 'strategic' higher order dynamic capabilities, by categorising them into three broad abilities, namely sensing, seizing and re-configuring (Gebauer, 2011, p.1240). Dynamic capabilities relate to a firm's strategic high-level competences that include activities linked to management's ability to sustain and amplify evolutionary fitness, thereby building long-run value for investors (Teece, 2007, p. 1344) and an ability to integrate, build, and reconfigure internal and external competences to address, and possibly shape, rapidly changing business environments (Teece, 2012 p.1395). Unlike ordinary capabilities, certain dynamic capabilities may be based on the skills and knowledge of one or a few individuals such as managers / management team rather than on organisational routines. As highlighted by Albort-Morant, Leal-Rodríguez, Fernández-Rodríguez, and Ariza-Montes (2018, p. 44) despite the several definitions of dynamics capabilities in key studies there appears to be an agreement on the core elements:

- (i) level of environmental change;
- (ii) organisational processes or routines;
- (iii) resources configuration,
- (iv) managers' decision making; and
- (v) learning mechanisms (Fukuzawa, 2015).

The notion of innovation capabilities (IC) extends the elaboration of AC as a multi-dimensional construct introduced the notion of 'dynamic capability' theory (ability to adapt and redeploy a capability) introduced by Teece, et al., (1997), Eisenhardt and Martin (2000), Zollo and Winter (2002) and Winter (2003 and 2013). A firm's ability to develop and deploy a range of innovation capabilities demonstrates its AC viewed as important 'core competency' for firms to be innovative by exploiting new knowledge acquired from external sources for economic gain. Innovation capabilities are a subset of the competences and capabilities allowing firms to sustain a competitive advantage by creating new products and processes to respond to changing market environment (Teece, et al., 1997). The literature is clear that the central role of dynamic capabilities is changing internal components of the firm and creating new routines (Teece, 2007).

Zahra, Sapienza, and Davidsson (2006, p. 918) define dynamic capabilities as the managerial ability *"to reconfigure a firm's resources and routines in the manner envisioned and deemed appropriate"*. Dynamic capabilities enable companies to respond to changes in the business environment such as

competition, crisis and failure (Zhang, Macpherson, and Jones (2006, p. 308). They avoid a competency trap, in which competencies become irrelevant due to changes in the business environment (Teece, 2007). Dynamic capabilities are beneficial in highly turbulent settings (Teece, 2007; Zahra, et al.,2006; Lichtenthaler, 2009; Engelen, Kube, Schmidt, and Flatten, 2014; and Sheng, 2017). Environmental turbulences (Sheng, 2017) are caused by changing global market conditions; the technological disruptions that propel the development of new products or the advancement of new processes, which can 'trigger' organisations to adopt new abilities and transform their business (Teece, 2017, p.10).

Ultimately, for a firm's success, it must keep its knowledge stocks replenished to maintain and increase their capabilities. This requires a continuous learning process particularly to acquire tacit forms of knowledge (Bougrain and Haudeville, 2002 p.737). Firms which introduce new products to the market place on a regular basis can improve business performance and contribute to regional economic development such as employment creation, expansion into existing and emerging new export markets, develop new industries, and create 'knowledge spillover' effects to the region. There is extensive evidence that university research, apart from being a valuable source of business innovation, generates local knowledge spillovers (Breschi and Lissoni 2001; Feldman and Desrochers 2003), which can contribute to the development of innovation systems (Jaffe 1989; Varga 1998; Anselin et al. 2000 in Muscio, 2013, p.715).

The AC concept relates to March's (1991) explanation of a firm's exploration and exploitation capacities to complement the internal capabilities of its business with abilities required to manage external relationships. March's two dimensions, along with the original AC construct, have been elaborated by various conceptualisations (Jansen, et al., 2005; Lane, et al., 2006; Todorova and Durisin, 2007 and Lev, Fiegenbaum, and Shoham, 2009). These studies address the enrichment of the AC concept, but the common tenet remains the same: *'by investing in certain (research or other capability building) activities, firms can improve their ability to identify value, assimilate and apply knowledge that is developed outside of the firm'* (Fabrizio, 2009 in Boly et al. (2014, p. 610). Similarly, Lucena and Roper (2016, p. 174) reveals, for firms to compete effectively in the short term and survive longer term, companies are required to generate *innovation streams or pipelines* defined as the ability of a firm to produce incremental and radical innovations simultaneously (Tushman, et al., 2010).

Incremental innovations allow a firm to improve its possibilities for maximising its fit with customer requirements, thus strengthening a firm's competitive position in the market (Schilling, 2012). Lucena and Roper's (2017) empirical study of the interactions and geographic location of Spanish manufacturing companies over the period between 2004 and 2011 provide evidence that firms' AC and ambidexterity in R&D serve as mediating mechanisms between technology alliance diversity and innovative performance. Businesses that balance their internal knowledge capability focus in R&D with use of external knowledge developed by a diversity of technology alliances are the firms

with better prospects to produce innovation streams. Firms that demonstrate higher levels of AC; adapt to new forms of innovation and technology; record lower incidences of firm mortality, and ultimately avoid the 'competency trap' (Swift, 2015, pp.1688-1689).

Further analysis by Swift (2015) demonstrates firms with higher levels of AC survive longer after a compact, significant increase in R&D spending. This suggests that firms with a stronger ability to explore and identify valuable external knowledge and assimilate it into their innovation processes have a better chance to survive an aggressive transition into exploratory R&D. The exploitation of knowledge to create economic value from collaborative research and development is problematic both from those that create knowledge and those that apply and use it. This dilemma stems across the entire innovation system, especially for the participants within an innovation system that seek to create economic value of new knowledge. When these two dimensions work together, they improve a firm's innovation competency, and a firm's propensity to innovate.

2.4.1 The diverse nature of Absorptive Capacity (AC)

The mere diversity of approaches taken to measure and understand how SMEs innovate, has led to relative gaps in the AC literature. In addition to the issues discussed above, relating to the focus on larger, more quantitative data, there is a need for additional empirical research that examines or confirms which external knowledge source is the best; how – and under what circumstances – this is best achieved by smaller firms. Which factors of the AC construct inform a firm's innovation product performance also remains unclear. The contribution and role of a firm's AC to successful industry–university collaborative outcomes are still relatively underexplored. Little empirical work highlights what these benefits look like in a pragmatic everyday business setting. These diverse gaps all relate to a common methodology issue, which is the lack of methods that enable 'storytelling' and interpretation of rich qualitative data, particularly in empirical studies, and especially for peripheral regions in an Australian context. This research aims to expand both the methodological and geographical boundaries of existing research.

At the same time, this study seeks to clarify the relationship between what has been called "internal" and "external" AC. Lewin and Massini, (2004) and Lewin, et al., (2011) have shown that innovative firms have a highly developed and distinctly superior capacity for learning compared with firms that are simply 'imitators'. Imitators will be less innovative; they may not introduce new products to the market regularly or are still developing an innovation and/or have abandoned the development of an innovation or lack sufficient commercial market interest. A firm's AC can be viewed by its internal capabilities i.e. the individual and firm (intra-organisational) and the firm's external capabilities namely its networks and relationships with other organisations (inter-organisational) (Lewin and Massini, 2004 and Lewin, et al., 2011). Success as an early adopter of a new management practice or an innovation is expected to depend on the extent to which an organisation adapts and implements the configuration of its internal and external AC routines (Lewin; et al, 2011, p.81). This study extends this literature by exploring whether the ability of a firm to discover and implement complementary

knowledge, which is created from different learning activities and routines between each AC phase, may explain why some firms are successful early adopters and most firms are imitators.

2.4.2 Limited knowledge of SMEs Absorptive Capacity (AC)

The contribution of university collaborations to the success of SME innovation performance has been examined in limited instances. Most recently (Fernández-Olmos & Ramírez-Alesón, 2017) claim only a few studies have attempted to study the effect of collaboration on firm performance and inconsistent results have been reported (Lin, Wu, Chang, Wang, & Lee, 2012). Firms that have developed their AC can show a range of innovation capabilities to engage in the wider innovation process and supporting systems available. These capabilities are said to be 'dynamic' and can reflect a wide range of alliance forms and knowledge collaboration types between industry and the university sector (Ankrah and AL-Tabbaa 2015). A useful potential 'operational framework' to an empirical investigation to measure AC, learning process and innovation capabilities is the recent work of Gebauer, Worch and Truffer (2012).

Gebauer, et al., (2012) examine the AC and strategic innovation business practices SMEs develop. They identify specific learning processes for knowledge management that achieve innovation performance (Gebauer, et al., 2012). Few studies have examined the role of AC on SMEs' NPD in particularly the role of industry-university R&D collaborations as a source of external knowledge to SMEs. When the focus is given to knowledge transferred between industry-university exchanges literature highlights the benefits and incentives to a firm's performance to be gained from R&D alliances, collaborations and partnering with a university (Teixeira, et al; 2013; Muscio, 2013, Biedenbach, Marell and Vanyushyn, 2018).

Increasingly, there is growing interest in the role of a firm's AC and interactions with universities (Grimpe and Sofkaa, 2009, Bishop, et al; 2011; Corral de Zubielqui, et al., 2016; and Kobarg, Stumpf-Wollersheim and Welp, 2017). Universities increasingly are being key partners for businesses, in the development of innovation. Interest in university-industry collaborations increased dramatically in the 1990s, corresponding to an increasing reliance of industrial policy on knowledge transfers as a tool for the development of knowledge intensive economies and increased competitiveness (Bozeman, 2000). Universities are an important agent involved with the traditional process of knowledge creation and this extends to their capacity and role to transfer and/or exchange new academic knowledge and technology research.

Gopalakrishnan and Santoro (2004) make a distinction between knowledge and technology transfers as contributing to fundamental different dimensions that influences the nature of innovation activities undertaken by a firm. This distinction is an important one to note; both adding 'value-creating' activities over time embedded within a range of inter-organisational collaborations. The knowledge embedded in people is more tacit and intangible whilst the knowledge set in procedural routines, technical specifications and equipment and machinery is more tangible. In the case of codified

knowledge outputs, an element of tacit knowledge (human expertise) is always required to get best value from the tangible item, which includes professional and highly skilled technicians such as machine operators to senior professional knowledge workers.

There is preference to adopt the term exchange rather than transfer, as the later implies a linear notion of the innovation and knowledge creation process. An exchange is more akin to current non-linear (Aribi and Dupouët, 2016) and multi-dimension views of innovation systems that seek economic commercial outcomes. Knowledge exchanges do not immediately imply innovation success, and can be directly or indirectly attributed to a firm's AC. The exchange is successful where the new knowledge makes an economic impact; when knowledge is applied within the business and creates value such as an economic benefit in the form of a new product. Knowledge and technology exchanges can occur through different collaboration arrangements and the success of such exchanges may reflect a firm's AC to a greater or lesser extent. Knowledge and technology are not interchangeable items. Their exchange between different actors varies across the phases of the NPD process as part of the innovation process.

At current rates of technological change and complexity no single SME can rely purely on its internal capacity; as such it needs to search elsewhere for complimentary resources from external knowledge sources. The use of external knowledge networks by SMEs is dependent on limits of the transaction cost theory and/or the benefits and savings that can be achieved by cooperation with external parties, particularly with a public research centre (Bougrain and Haudeville 2002, pp.736-737). Traditional university knowledge and technology exchange processes can take place through formal and informal channels. Formally, this can occur with a legal contract on a patent or on collaborative research activities; informal exchange channels refer to personal contacts and hence to the social tacit dimension of knowledge exchange. Supporting such alliances, collaborations and strategic partnerships to encourage knowledge production and exchange by other regional participants can enhance a regions innovation capacity.

The relative importance of the external knowledge source can depend on the firm size and technological capability factors. The knowledge exchange mechanism under study can be referred collaborative learning – that occurs between firms and a university. This can be a two-way learning transaction process but may involve other parties in various strategic alliances and partnerships across industry and university networks (Huggins & Prokop, 2017). Organisationally, such collaboration is manifested in multiple ways. The most frequent types of interaction are represented by collaborative research, contract research, and consulting (Perkmann and Walsh, 2007). Collaborative research refers to arrangements under which universities and industry co-operate to pursue research objectives together. Contract research consists of research carried out by universities under the direction of industry clients (Meyer-Krahmer and Schmoch, 1998). Academic consulting consists of advice and expertise provided by academics to industry clients, usually for personal compensation (Perkmann & Walsh, 2008).

2.5 Innovation Characteristics for SMEs

To understand the capacity of SMEs to be, and remain competitive, over a business lifecycle, it is important to appreciate the context of the global market. This involves understanding SMEs characteristics. SMEs have characteristics and difficulties (Pierre and Fernandez, 2018, pp.146-147) unique to their organisational structure, responses to the environment, managerial styles, and the ways in which they compete with other rival firms. These factors alone make the study of SMEs a rich research field. The study of SMEs innovation capacity needs to be embedded with an understanding of their specific characteristics. Three characteristics that influence SME innovation capacity broadly include:

1. **SMEs have scarce resources that drive common activities.** The need for resources is not equal for all SMEs and depends on the firm's environment. SMEs are consistently seeking suitable human, financial and technological resources to achieve their innovations. As SMEs operate on thinner available resources. They can be successful developed internally or accessed from external sources. This can lead to efficient internal processes to knowledge and project management.
2. **Firms develop external partnerships and inter-organisational collaborations with customers, suppliers and research centres such as universities.** These activities are developed at different phases of the innovation processes to develop new products, from early exploratory R&D, prototype design engineering, commercialising and marketing stages of NPD. Innovation activities are heavily directed by strategic leadership and vision from executive business managers and venture capitalist entrepreneurs. Two characteristics that impact on this point include the personal experiences, knowledge competencies and abilities of the entrepreneur involved. The personality and behaviour of the business owner/manager, particularly about risk taking and willingness to innovate, ranging from collaborative or protective strategies, are important considerations.
3. **SMEs tend to compensate for their lack of internal resources by being agile and flexible.** With little hierarchy and less complex structures, they can easily integrate market needs and technological changes. This is essential to respond to rapidly changing environments. Their size and less formality can position SMEs to interact with external members quickly to enhance communication, collaborations and improve outcomes. However, their size can limit the number of innovation activities that can be efficiently managed, making product innovation management difficulty due to costs associated with projects with shorter term market and turnaround timeframes (Pierre and Fernandez, 2018, pp.151-152).

The innovation process and knowledge management literature are diverse and little consensus exists in the definition of SMEs innovation capacity. The differences are borne out in the literature review and the research of others. Several factors are attributed to this (Pierre and Fernandez, 2018, p.147) include:

- Only a third of firms had a deliberate innovation strategy – and for most – innovation is embedded and ‘lost’ in the day to day operational activities of business. Rarely are they demarked due to the difficulty to distinguish them from overall general business activity.
- Previous research has ignored or given insufficient regard to SMEs’ specific characteristics, and few models have been developed specifically in context for SMEs to build an innovation capacity framework.
- Lack of and/or the ability to attribute generic attributes to SMEs innovation capacity. A diversify and heterogeneous approach is advocated but little consensus has been researched. This leads some to advocate that this is not a significant research problem and encourage future research to focus on dominant characteristics shared by innovative SMEs (Pierre and Fernandez, 2018, p.147).

Pierre and Fernandez (2018) identified fourteen dimensions from the literature that related specifically to SMEs, of which ten were considered most relevant including: Owner/entrepreneur characteristics; Network integration; User/customer integration; Institutional support; Innovation strategy and planning; Culture and structure; Innovation process management; Learning process; Innovation-dedicated resources; and Processes reevaluation.

Table 1: Dimensions to SMEs Innovation Capability (IC)

Dimensions to SMEs Innovation Capability (IC)	Score from Pierre and Fernandez multiple case studies (2018)
1. Institutional support	74
2. Resources dedicated to innovation	70
3. Network integration	68
4. Access to cash flow	65
5. Innovation strategy and planning	61
6. Standard and regulation integration	61
7. Owner/Manager characteristics	58
8. Innovation process management	54
9. Access to private funding	54
10. Strategic management of IP	54
11. Learning process	53
12. Users integration	52
13. Process Re-evaluation	39
14. Conditions for innovation	38

Of these fourteen, ten appeared relevant to various degrees (high, medium or low) among the thirty-two SMEs they case studied. Firstly, they identified among the ten dimensions of SMEs’ innovation capacity only four appeared to be highly relevant:

- (i) Network integration,
- (ii) institutional support integration,
- (iii) innovation strategy and planning; and the

(iv) resources dedicated to innovation.

These dimensions were found to be essential for SMEs' innovation capacity and the most pertinent to this study. The importance of context, and the complexity of possible factors, points to the importance of additional qualitative case study research in this area. Secondly, their results highlighted four dimensions of SMEs' innovation capacity as relevant for SMEs' innovation capacity and thus as an important factor in SMEs' innovation performance: (i) Business owners/manager characteristics, (ii) user integration in the innovation process, (iii) innovation process management and the (iv) learning process. These four dimensions are presented as important factors. Thirdly, among the different dimensions one dimension previously highlighted emerged as a poor determinant of SMEs' innovation capacity: (i) SMEs' corporate conditions for innovation. This dimension has been presented as an inherent characteristic of SMEs that does not need specific investment or attention and appeared to have little relevance. This result questions the impact of SMEs' specificity on innovation capacity. Fourthly, ambiguous results regarding the (i) the innovation strategy and process re-evaluation. Some SMEs considered this to be a key dimension, while other SMEs did not mention it. These findings question previous studies regarding strategy and process re-evaluation.

2.6 Innovation Systems and External Knowledge Source Partners

To understand the diverse networks of external knowledge sources, firms need to consider: the source and type of knowledge they require; the breadth and depth of their existing networks; and how integrated or 'central' they are in relation to regional, national and global networks (Tsai, 2001). The external network of regional SMEs can contribute to its high performance (Huggins and Johnston (2009 and 2010), Huggins and Thompson (2015 and 2014)). The role of knowledge is critical to the innovation processes as it relates to two important innovation modes – namely ST&I and DU&I. Jensen, Johnson, Lorenz and Lundvall (2007) argued that Science, Technology and Innovation (ST&I) mode, is based on the production and use of codified scientific and technical knowledge. The other, the Doing, Using and Interacting (DU&I) mode, relies on tacit exchanges, informal processes of learning and experience-based on 'know-how'. Jensen, et al., (2007) study showed groups of firms that practice both modes together with different intensities are more likely to innovate with new products or services than those relying primarily on one mode or the other.

Entrepreneurial SMEs are firms that engage in deliberate innovation activities to seek a competitive advantage in the market which contributes to a wider range of entrepreneurial discovery functions. Increasingly, product innovation is a co-creation process, adding value between different participants of the supply chain such as suppliers, customers, or competitors. The key ingredient is the collaborative learning and their actions within this network of participants (supply chain). These network exchanges improve with reliability and trust, which requires frequent face to face interactions and exchanges. This makes the nature of knowledge both an interactive and social phenomenon. The role of tacit knowledge and the 'doing, using and interacting' (DU&I) research mode of knowledge

creation is highly valuable. The role and nature of external networks of knowledge source relates to issue of proximity, which pertains to concepts of social network theory (Gilsing 2005, pp. 25-26).

More specifically, research attention has given accounts of why some regional areas are more successful than others in developing and implementing continuous improvements of their knowledge bases and network structures (Cappellin, 2009, p.157 in Cappellin and Wink), as well as analyses of growing inequalities of sustainable activity, development and growth between metropolitan and non-metropolitan regions. SMEs rely on external sources of knowledge for R&D and other innovative activities, and this has predominantly been from customers, competitors and suppliers in the supply chain system. In the case of many SMEs, universities and research institutions tend to be the lowest source of external knowledge. The firm will anticipate the application of acquired knowledge will be adopted or assimilated without major transformation of the internal business operations and routines.

The acquisition of new knowledge – in the form of tangible items such as standard digital technology, equipment and machinery – requires lower order learning competencies relating to operational routines. This form of knowledge will not contribute to radical innovations and is therefore limited to lower order forms of innovation outcomes. In contrast, external knowledge inflows from ‘science-based’ actors or ST&I influence innovation indirectly, via AC, and therefore requires assimilation and or transformation phases to make sense of the new knowledge to the business. Largely, for new knowledge to create economic value, a level of interpretation and re-interpretation is required to produce unanticipated outcomes through the NPD process.

This is consistent with AC theory that suggests firms derive innovation benefits from new external knowledge only if they recognise its value, internalise, and exploit it (Cohen and Levinthal, 1990; Zahra and George, 2002). Corral de Zubielqui, et al., (2016) suggest that there is a need to delineate external knowledge flows by specific actors, as the circumstances in which AC transforms external knowledge inflows into innovation are not universal or guaranteed, in line with recent work (Moilanen, et al., 2014). They reveal that external knowledge inflows from science-based actors are positively associated with AC, in line with Moilanen, et al.’s (2014) findings. Finally, Corral de Zubielqui, et al., (2016) results reveal that AC has a two-fold effect:

- (i) a positive direct effect on innovation outcomes; and
- (ii) an indirect effect on firm performance through innovation, consistent with theoretical expectations (Cohen and Levinthal, 1989; Zahra and George, 2002) and some empirical evidence (Kostopoulos, et al., 2011).

These results, together with the indirect effect of knowledge inflows from science-based actors on innovation via AC, underline the importance of AC to innovation outcomes and ultimately, firm performance (Corral de Zubielqui, et al., 2016, pp.18-19). Innovation networks are a specific mode of this arrangement. The emergency of knowledge flows and networks are explained not by transactions costs considerations, but by strategic relational capacity interests, the wish for

knowledge 'appropriability', and realising the synergetic effects resulting from technological and a balance of knowledge similarity and dissimilarity (usually operationalised as complementary resources or capabilities) (Freeman, 1991, p.512).

Jones and Corral de Zubielqui (2017, p.264) highlight the literature that examines the role of prior research on networks and open science, the increasing importance of sourcing knowledge from external organisations such as universities in particular (Cohen et al., 2002; Hansen and Klewitz, 2012; Perkmann et al., 2011; Perkmann and Walsh, 2007; Powell and Grodal, 2005). However, empirical evidence of the impact of direct links between universities and firms is weak and inconsistent (Bekkers and Freitas, 2008; Dornbusch and Neuhäusler, 2015), including in the sustainability-oriented innovation SME context (Klewitz, 2015). Fernández-Esquinas et al. (2015) note that the difficulty in translating scientific results into the market is well established, raising important questions with respect to how to maximise benefits from universities and related research institutes for skills and development (OECD, 2007), especially in peripheral regions in which the industrial fabric is composed of many SMEs with low absorptive capacity (Fernández-Esquinas et al., 2015).

2.7 Absorptive Capacity and SMEs Innovation Capability

This section positions AC more broadly in context of studies that examine business innovation ability or capabilities. Most studies on innovation capabilities focus on technological innovation. These innovations are the result of technological and NPD capabilities that require a proper innovation strategy and planning (Pierre and Fernandez, 2018; Vicente, Abrantes, and Teixeira, 2015). Innovation strategy and planning refers to the innovative position designed by a firm that depends on its competitive environment (Dyer, Singh, 1998), its resources and its competencies (Helfat, Peteraf, 2003; Leonard-Barton, 1993; Prahalad, Hamel, 1990; Ramanujam, Mensch, 1985; Tidd et al., 2013; Teece et al., 1997, 2007). Strategic market scanning may reduce the risks of excessive dependency on SMEs' industry supply chain, as well as market vulnerability due to evolving competitive and technological environments (Marchesnay, 2014). Innovation strategy should fit the firm's business strategy (Sundbo, 1997). The innovation strategy should support the firm's competitiveness in its environment (Leonard-Barton, 1993; Teece et al., 1997, 2007; Tidd et al., 2013). SMEs with formal strategic design and planning seem to achieve better results (Mazzarol, et al., 2009; Berman et al., 1997; Porter, 1991); in particular, they achieve better innovation objectives (Rothwell and Dodgson 1991; Terziovcki, 2010).

Firms may present different types of innovation throughout their lifecycles, and not all reach a technological frontier; other innovation types (process, organisational or marketing) derived from the other capabilities may explain their marketplace successes. There are many studies that measure a firm's innovation ability directly as shown in table 2 below (Boly et al., 2014, pp. 609-610). On the back of these studies, Boly, et al., (2014) presents a measurement framework based on fifteen innovation management practices derived from a sample group of thirty-nine SMEs across the

'Lorraine' Region in North-East France. These fifteen measures are informed by the broad tenets of both the AC and dynamic capabilities literature (Boly, et al., 2014, pp. 609-610). In terms of dynamic capability theory the relevancy to business innovation relates to the shifting character of the environment and secondly the key role of strategic management to appropriately adapt, integrate and re-configure internal and external organisational skills, resources, and functional competences toward changing environment (Boly, et al; 2014, p.609).

Table 2: Innovation metrics and aggregation methods

Authors	Evaluated Factors	Aggregation method	Application
Chiesa et al. (1996)	Concept generation	Descriptive profile of the factors	British Industry
	Process innovation		
	Product development		
	Technological acquisition		
	Leadership		
	Resources		
	Systems and tools		
Yam et al. (2004)	Learning capacity	Parametric identification (multi-linear regression)	Identification of innovation factors in China
	R&D capacity		
	Resource allocation		
	Manufacturing capacity		
	Marketing		
	Organisational capacity		
	Strategic planning		
Guan et al. (2006)	Learning	DEA (Data Envelopment Analysis) (input-output model)	Innovative companies in China
	R&D		
	Manufacturing		
	Marketing		
	Organisation		
	Resources		
Nemery et al. (2012)	Six meta-practices	Choquet Intégral	French companies receiving innovation awards
Fernandez de Canete et al. (2012)	Exploratory factors of innovative companies	Descriptive statistics	Spanish Biotech sector
Wang et al. (2008)	R&D capacity	Fuzzy integral	Chinese high-tech sector
	Decision aid tools		
	Marketing		
	Manufacturing capacity		
	Capital		
	Technical innovation technique	AHP (Analytic Hierarchy Process) Tsai et al. (2008), Wang and Chang (2011)	Chinese high-tech sector
	Product		
	Process		
	Managerial innovation		
	Creativity		
	Marketing		
	Organisation		
	Strategy		
	Strategic planning	Hybrid Fuzzy-MCDA Cheng and Lin (2012)	Main board electronic sector in China
	Marketing		
	Innovation infrastructure		
	Knowledge and skills		
	TICs capabilities		
	External environment		
Manufacturing capabilities			

AC gives priority, first, to the study of activities (capability building), and second, to knowledge as a resource. For example, Boly, et al., (2014, p.610) propose 15 measures to innovation capability, without specifically exploring which measured pertain to either AC or dynamic capability theory. Examining the definitions provided by Boly, et al., (2014); eight of these measures relate to dynamic capacity theory and seven relate to AC learning activities, which include:

1. **Innovation process improvement:** tasks allowing an ongoing evaluation and improvement of the NPD process (methodologies, tools among others).
2. **Competitive technology intelligence activities:** survey tasks, such as technological, competitive, economic, etc., organised to open the company to its external environment.
3. **Network management:** top management tasks concerning the management of networks in which the company operates.
4. **Collective learning:** tasks relating to the management of a suitable collective learning environment during the project.
5. **Ideas research/Creativity:** continuous tasks concerning the emergence of new ideas from research, marketing or employee suggestions to sustain future projects.
6. **R&D activities:** tasks relating to fundamental knowledge acquisition and creation.
7. **Customer relationship management (CRM):** tasks stimulating the integration of customer knowledge and its sensitivity to the company's products.

More recently Sciascia, D'Oria, Bruni, and Larrañeta (2014) More recently Sciascia, et al., (2014) study of 103 medium-sized Italian firms confirmed a hypothesis that, in low and medium-technology industries (LMT) industries, Entrepreneurial Orientation (EO) has a positive effect on firm performance when coupled with high levels of both Potential and Realised AC. By contrast, innovative, proactive and risk-taking behaviours could be ineffective if realised without a well-developed capability to acquire new knowledge to be combined with the existing knowledge stock for incremental innovation. This result implies that EO effectiveness is strongly determined by AC in LMT industries and that, without this capability, entrepreneurial behaviours are ineffective. Such studies highlight the importance of the AC concept to understand successful innovation in regional SMEs.

2.8 Quantitative AC Empirical Studies

Research into the AC concept has predominantly been undertaken on larger firms, but increasingly research is examining smaller firm sizes. Consistently, these studies adopt the four dimensions of the Zahra and George (2002) elaboration of the construct, which this research also uses. When the research literature is narrowed further, the discussion centres on key debates over:

- which source of external knowledge source improves a firm's innovation performance the most across the different types of external knowledge sources (customers, suppliers, competitors and universities)
- how AC develops across large and small firms of different technological (low, medium and advanced) base,

- the effects of different knowledge bases (analytical, synthetic and symbolic); and
- consideration of the variety of 'proximity dimensions' (Boschma, 2005, Asheim, 2007, Boschma and Frenken, 2010, Asheim, Boschma et al. 2011, and Mattes, 2012).

Empirical studies, using different methods (surveys, archival data, and case studies) and studying different contexts (firms, joint ventures, different industries) have increased our understanding of AC. Useful schematisation of the empirical work undertaken to date have been carried out by a number of authors (Volberda, Foss and Lyles (2010, pp.936-937), Flatten et al (2011a), Duchek (2013, p.315-321), Lewin, et al., (2011, p.83)) Table 2 below summarises some of the diversity of measures and indicators used.

Table 3: Examples of Quantitative AC Studies

Quantitative studies of Absorptive Capacity		Literature Examples
Classifications	What is measured	
Indicators	Input-oriented	R&D efforts <ul style="list-style-type: none"> • R&D expenditure (Rocha (1999). • R&D intensity (Stock et al. (2001). • Existence of a formalised R&D department (Becker and Peters (2000).
		R&D human capital <ul style="list-style-type: none"> • Percentage of R&D personnel with a doctorate degree (Veugelers (1997), • R&D employees divided by total employees (Gao et al. (2008).
	Output-oriented	R&D patents and publications <ul style="list-style-type: none"> • Number of publications (Cockburn and Henderson (1998) • Number of patents (George et al. (2001) • Cross-citation rate (Mowery et al. (1996).
Perceptive instruments (questionnaires)	One dimensional	AC at the operational level <ul style="list-style-type: none"> • Szulanski (1996) designed questions to capture the ability to value, assimilate, and apply new technology.
	Multi-dimensional	Multiple components of AC <ul style="list-style-type: none"> • Jansen, et al. (2005) developed multiple items for every component of AC as defined by Zahra and George (2002).
	Single components	Single components of AC <ul style="list-style-type: none"> • Nieto and Quevedo (2005) designed questions that refer to the links between the firm and the surrounding environment.

Of particular interest, Volberda, et al. (2010, p.934) undertook a bibliometric analysis of 1,213 publications from 1992 to 2005, to map contributions, constructs, and implications of AC in six major organisational theories: learning, innovation, managerial cognition, knowledge-based view of the firm, dynamic capabilities, and co-evolution. They concluded by developing an integrative framework (Figure 3 below) of the concept that identifies the underlying dimensions that affect how the concept is made operational; its multi-level antecedents (managerial, intra-organisational, inter-organisational); and its outcomes, and the contextual factors (environmental conditions, prior related knowledge).

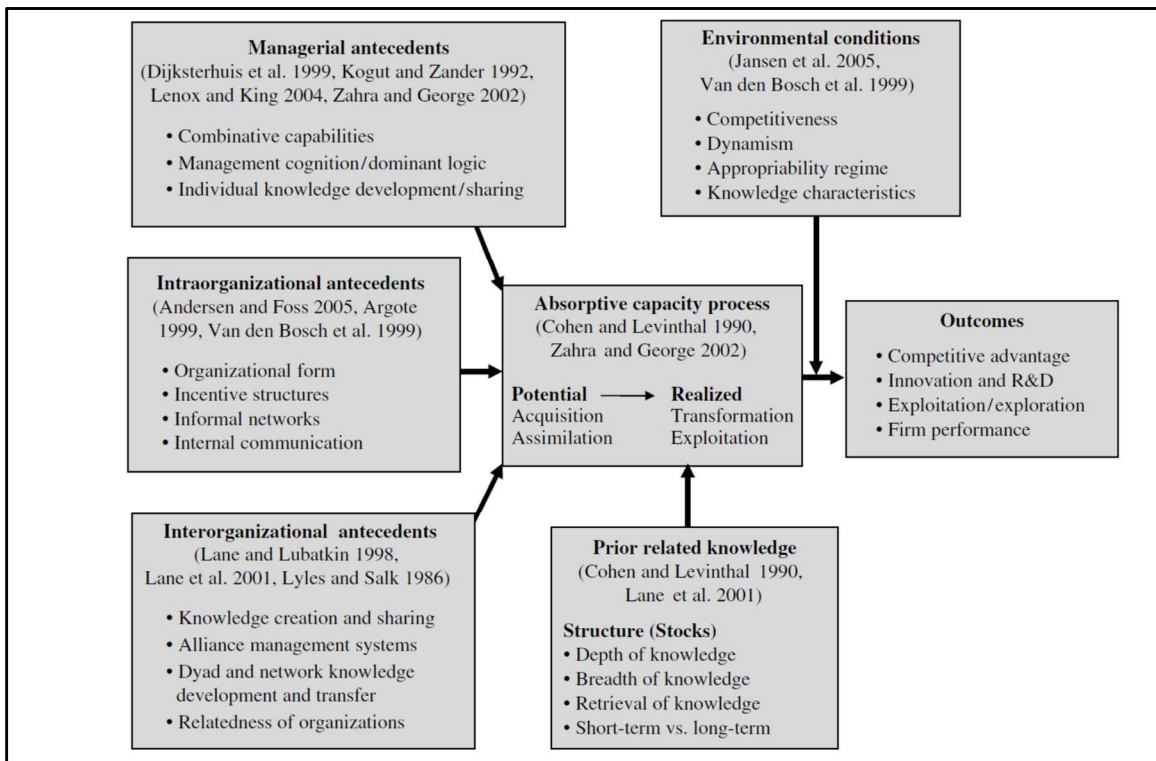


Figure 3: Integrative framework - AC antecedents by Volberda, Foss and Lyles (2010, p.941).

The criticisms of quantitative research approaches to literature caused Lane, et al; (2006, p.858) to suggest that “AC should be empirically explored in non-R&D contexts using metrics that capture each dimension of the AC process in a manner appropriate for that context.” More recently research has adopted a mixed method approach that combines traditional quantitative business innovation surveys with an analysis of structured interviews; or a questionnaire from random sample of firms to give a broader qualitative understanding to the concept. The use of qualitative case studies or survey instruments normally using self-reports to make attributions about AC (e.g., Szulanski 1996, Lane and Lubatkin 1998, Lane, et al. 2001 and 2006). A limited series of studies (e.g. Jansen, et al., 2005; Lane, et al., 2001; Liao et al., 2007; Vinding, 2006; Tu et al., 2006; Wong et al., 1999) attempt a more in-depth study of this process to create a multi-dimensional framework that embody AC to include: combinative capabilities (systematisation, coordination, and socialisation of knowledge); methods of compensation; dominant [management cognition] logic; knowledge base; management practices; strategic business strategy; organisational structure; information management systems; and organisational culture.

Other empirical studies make contributions to the role of AC in innovation, firm adaptation, successful strategic alliances, and knowledge creation (Lewin, Massini and Peeters, 2011, p.83). As summarised by Lewin, et al., (2011, p.83) there is a lack of direct observation or measurement of the routines that derive AC, and there is a need to better understand and make the AC concept operational. These shortcomings suggest a need for a more valid measure that captures the multiple dimensions of AC. Apart from these quantitative economic streams of understanding there are a range of management studies that seek further qualitative understanding, to account for more

intangible considerations as an indicator to a firm's innovation ability and performance. A multi-dimensional model developed by Lewin, et al; (2011) attempts to untangle the various approaches to absorptive concept by exploring practiced routines as an expression of 'meta-routines'.

In their model, they develop earlier work of Lewin and Massini (2004) to decompose the construct of AC into two components; internal and external AC capabilities, and identify the configuration of meta-routines underlying these two component. They apply the concept of meta-routines (Nelson and Winter 1982, Feldman and Pentland 2003) to propose several meta-routines underlying the internal and external dimensions of AC, building on and extending the categories proposed by Lewin and Massini (2004). Meta-routines are the theoretical micro-foundations of AC, expressed in various organisations in different or similar ways, and in different combinations, as actual practiced routines. Practiced routines take the form of rules, procedures, norms, or habits that are contextual and idiosyncratic to each organisation. They embody codified (explicit) as well as tacit (implicit) knowledge, and their knowledge basis is assumed to evolve through many different learning mechanisms and processes including '*problemistic search*', '*trial and error*', '*improvisation*', '*learning by doing*', '*directed search*', '*formal reflection and adaptation*', and '*variation and selection processes*' (Lewin, et al; 2011, p.86). As this discussion suggests, the methods used to study the AC concept are diverse and, at times, ambiguous. There is no standard measure, definition, or operationalisation of the concept (Duchek, 2013, p.315). This diversity in theory and method complicates the extent to which findings generalise. It therefore cannot be presupposed that findings from studies undertaken in contexts very different from regional Australia, will apply fully to Australian regional SMEs.

2.9 Qualitative AC Empirical Studies

Compared to the more extensive quantitative literature, only a few qualitative studies have analysed AC. These studies provide insights into the historical development and changes of AC in organisations. However, these studies are based on different theoretical models of AC (Duchek, 2013, p.321). For example, Kim (1998) assumes prior knowledge and learning efforts are the two major elements of AC and uses the example of the Hyundai Motor Company to illustrate these elements. Kim pictures the process of advancing AC and shows that Hyundai acquired external knowledge to expand its prior knowledge base and proactively constructed crises to increase the intensity of effort in organisational learning. The example illustrates how the firm became one of the most dynamic automobile producers in developing countries. To capture the prior knowledge base and learning efforts, Kim (1998) makes use of interviews with executives in manufacturing and R&D, supplemented with firm records and plant tours.

Jones and Craven (2001), Jones (2006), and Easterby-Smith, et al; (2008) adopted a routine-based perspective on AC. Using interviews and participant observation, they focused on specific absorption processes or explicitly refer to (more and/or less successful) routines of AC. In a longitudinal study by Jones and Craven (2001) illustrated the development of AC by analysing the firm's activities over a two-year period by participating in a company learning program and acting as participating

observers. Thus, they concluded that improving AC requires the development of new coordination capabilities that help codify. Jones (2006) investigated the influence of individual agency on AC by conducting interviews with all senior managers and departmental managers directly involved in the change. Easterby-Smith, et al; (2008) went one step further to analyse three cases across different industries. Their data sources centred especially on interviews, documents, and observations of formal and informal meetings.

Table 4: Examples of Qualitative AC Studies

Qualitative Studies of Absorptive Capacity		Literature Examples
Classifications	What is measured	
Case studies (interviews, observations, archival data)	Single cases	AC, influencing factors and outcomes
	Multiple cases	AC, influencing factors and outcomes

The authors gathered data by tracking the evolution of major changes and innovations between 2003 and 2005 and focused on processes leading to the adoption and implementation of ideas. The authors provided some practical illustrations of how firms deal with external knowledge. Unfortunately, they presented only one story per organisation. Within each organisation, they followed specific stories and events to illustrate the internal absorption processes and identify different features of AC. They argued that a process perspective on AC should particularly include the role of power in the way knowledge is absorbed by organisations and provide a better understanding of the nature of boundaries within and around organisations. These limited examples illustrated knowledge absorption practices in specific organisational contexts. They did not provide any information about the concrete practices that underlie individual components or capabilities of AC, and they did not explain what contribution these practices make to successful knowledge absorption. As such, this research gap can be filled by applying a practice-based approach in line with Cook and Brown (1999) as discussed by Duchek, (2013, p.322). Considering such criticisms, there have been more recent attempts and advances to derive a more valid approach that captures the multiple dimension of AC, including Flatten, Engelen, Zahra and Brettel, 2011(a), Gebauer, 2011, and Gebauer, Worch, and Truffer, 2012. The current research contributes to this developing area of research.

2.10 Recent AC Models

Despite the growth of AC studies, few have addressed the learning processes in detail and how they change over time. This section discusses the few alternative AC models that have been developed, as summarised in table 5 below. Lane, et., al. (2006) discussed how AC has gone through a process of reification and refined the original Cohen and Levinthal (1990) model by introducing a sequential process: (i) recognising and understanding potentially valuable new external knowledge through exploratory learning; (ii) assimilation of new knowledge through transformative learning; and (iii) using the assimilated knowledge to create new knowledge through exploitative learning. Lane, et al., (2006) point to the fact that feedback loops exist between exploitation and the two other phases. They postulate that outputs produced at the end of the exploitation phase can modify the way exploration and exploitation will be conducted in the future. More precisely, what has been achieved at the end of an absorptive effort modifies the organisational context, representations held by the different actors, and the firm's strategy. These different elements, in turn, will affect the way the absorptive process will unfold in the next round. Thus, congruent with organisational knowledge creation accounts based on an epistemology of practice, works attached to modelling absorptive capacity point to the possibility of finding non-linearities and feedback loops at different points of the process. Yet, to our knowledge, we still lack a presentation of absorptive capacity that would fully integrate such loops (Aribi and Dupouët, 2016, p.17).

Todorova and Durisin (2007, pp. 783-784) introduced one of the few AC modifications in the future research avenues recommended by Zahra and George (2002). Todorova and Durisin (2007) encourages further research on transformation of knowledge structures during absorption and suggest that the drivers of transformation might differ from the drivers of assimilation. The suggestion directs the attention of researchers to the antecedents of AC - both their relative importance and the exploration of new antecedents. They also proposed that future researchers investigate more complex mechanisms of relationships between transformation and assimilation that consider the multilevel aspects and high complexity of organisational learning. The research literature shows that the innovation performance of SMEs is improved with a well-developed AC. This is one of the key research objectives to be addressed to show how some of the typical innovation barriers and obstacles to SMEs can be encountered.

The qualitative case study adopted will identify innovative capabilities that enhance a firm's AC. The approach to the research is viewed from a two-pronged perspective as follows.

1. Firstly, this problem is studied primarily from the firm's perspective in terms of its innovative capabilities developed to enhance a firm's AC by collaborating with a university.
2. Secondly, the research provides insights for a university, in terms of their experiences working with SMEs – to exchange scientific knowledge and technology.

Both perspectives will shed light to research and development capacity of such institutions to produce knowledge for regional businesses. The nature of a university's innovation capacity, specifically to

collaborate and exchange new knowledge to industry, raises a raft of other considerations worthy of investigation, beyond that of its traditional roles of education and teaching. The overall research problem being addressed relates to several matters that inform and influence a firm's innovation competency. A firm's innovation competency relates to its use of external knowledge sources that can be enhanced with geographical proximity (physical location) that includes 'accessibility' in terms of distance and/or time it takes to travel between places. Furthermore, a firm's competency will be determined by a range of non-physical proximity dimensions such as cognitive, institutional, organisational, and social (Boschma, 2005).

Todorova and Durisin (2007, p.775) study reinstates the role of 'recognising the value' of external information the original first component in Cohen and Levinthal's (1990) conceptualisation. Todorova and Durisin (2007) relies on learning theories to assert that transformation of knowledge is not the step after knowledge assimilation but represents an alternative learning process linked to assimilation by multiple paths; stating the neat distinction between Potential and Realised AC does not hold any more. In addition, these assimilation pathways reposition the role of social integration mechanisms and power relationships and suggest the need for incorporating feedback loops for a dynamic representation of AC. Lane, et al., (2006) and Todorova and Durisin, (2007) emphasises three learning dimensions of:

(i) exploratory (recognise), (ii) transformative and (iii) exploitative learning (Lane, et al., 2006);

• **AC1 - AC3 - AC4**

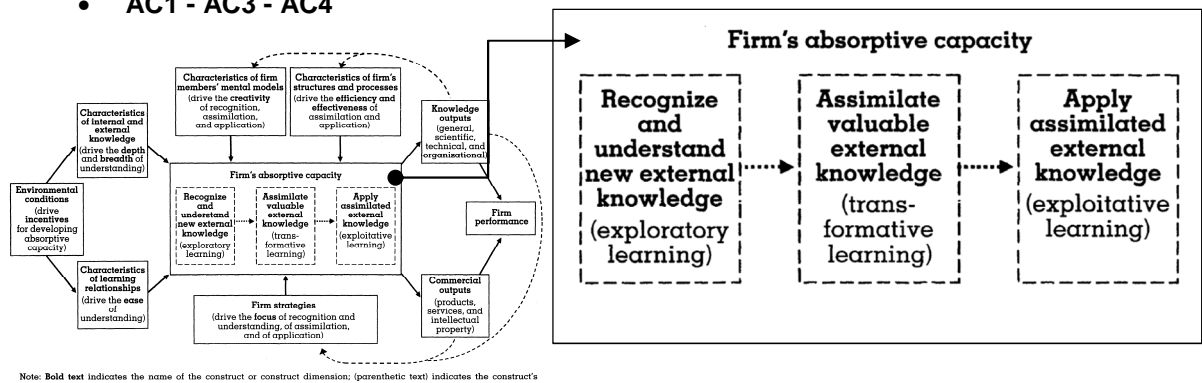


Figure 4: Lane, et al., (2006, p.856) AC Model

OR

(i) acquisition, (ii) assimilation or transformation, and (iii) exploitation (Todorova and Durisin, 2007).

• **AC 1- [AC 2 or AC 3] - AC 4; or more specifically being:**

- AC 1 - AC 2 - AC4; or
- AC 1 - AC 3 - AC 4.

Todorova and Durisin's (2007, pp.775-776) make a distinction between assimilation and transformation, refer to figure 5 below. Assimilation suggests firms integrate new knowledge into their existing internal business routines and structure without requiring substantial transforming of their operations to apply it for commercial gains. Transformation occurs when firms are unable to assimilate new knowledge easily and need to change their existing internal arrangements. Existing innovation activities and routines are either revised or new ones developed and deployed to make

sense of the acquired knowledge to inform NPD and launch to its market to realise a commercial gain. Zahra and George (2002) argue that the contingent conditions under which AC leads to competitive advantage have been overlooked in previous research.

Todorova and Durisin (2007) identify activation triggers, social integration mechanisms, and appropriability regimes as the key contingencies, along with adding new feedback links. Although Zahra and George (2002) characterise AC as a dynamic capability that fosters organisational change and evolution, they do not use ‘thinking cycles’ typical of evolutionary approaches to management studies and, thus, fail to capture the dynamics and complexity of the phenomenon (Todorova and Durisin, 2007). A recent study by Patterson and Ambrosini (2015) extends the non-sequential / non-linear AC perspective and concluded by stating “we empirically found that assimilate, transform and exploit were iteratively linked but we also discovered that the process was configured with assimilate coming before and after ‘acquire and search’ for being added to the recognise value process” (p.88).

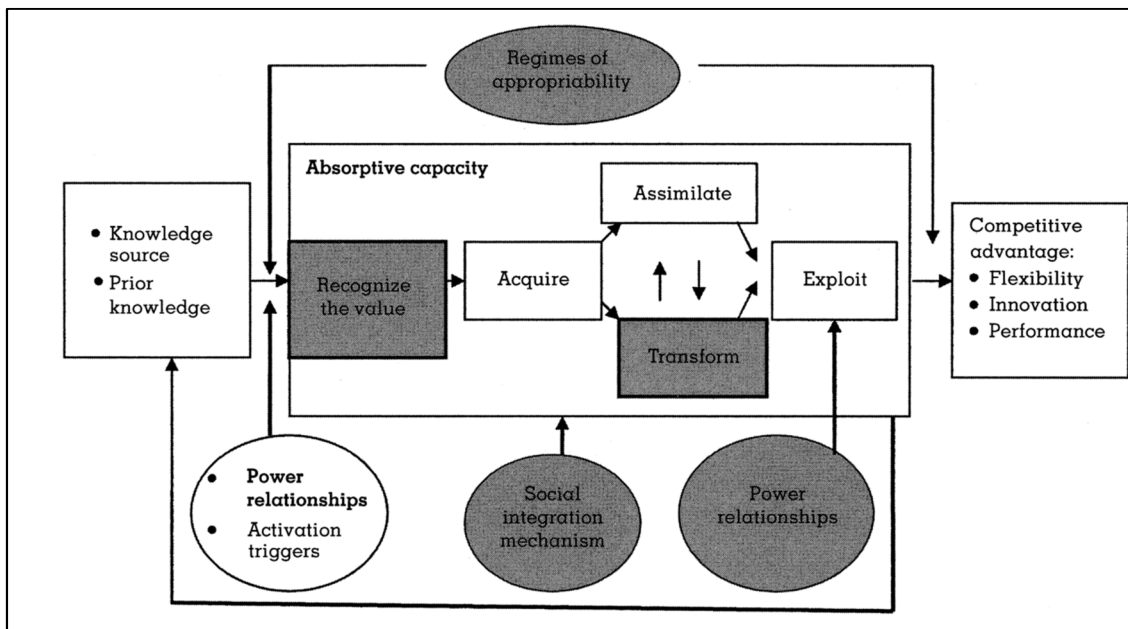


Figure 5: Todorova and Durisin's AC Model (2007, p.776).

Patterson and Ambrosini (2015) results indicate that the AC construct existed in biopharmaceutical firms they examined; the configuration was not as suggested by Zahra and George (2002). They conclude that the Todorova and Durisin (2007) construct is an empirically supported extension of Zahra and George (2002) construct, with suggested modifications to the ‘assimilate’ and ‘recognising value’ components. Patterson and Ambrosini’s (2015) research states that transformation and exploitation are continuous and iterative learning processes throughout the product development process, and requires organisational support provided in an iterative dynamic manner. Additionally, there is a need to continuously assimilate external partner information throughout the transform and exploit phases of AC. This suggests that collaboration and alliance management, as well as project management capabilities, play an important moderating role in the assimilation of external knowledge during the later stages of AC (Patterson and Ambrosini, 2015, p.88) – for firms to achieve Realised AC. Unlike more recent AC models, Zahra and George (2002) viewed acquisition as a single process.

Todorova and Durisin's (2007) added the need to 'recognise value' whilst Patterson and Ambrosini (2015) compose acquiring knowledge into two separate elements of: (i) 'search for and recognise value' and (ii) 'acquire', see figure 6 below. For all firms, 'search for value' is viewed as a very important set of activities. All the interviewees indicated the biopharmaceutical firms perform some type of opportunity searching whether it is active or passive. The 'search for and recognise value' process for these firms do not occur in a temporary nor simultaneous manner, but rather 'search for and recognise value' occurs before 'acquire'.

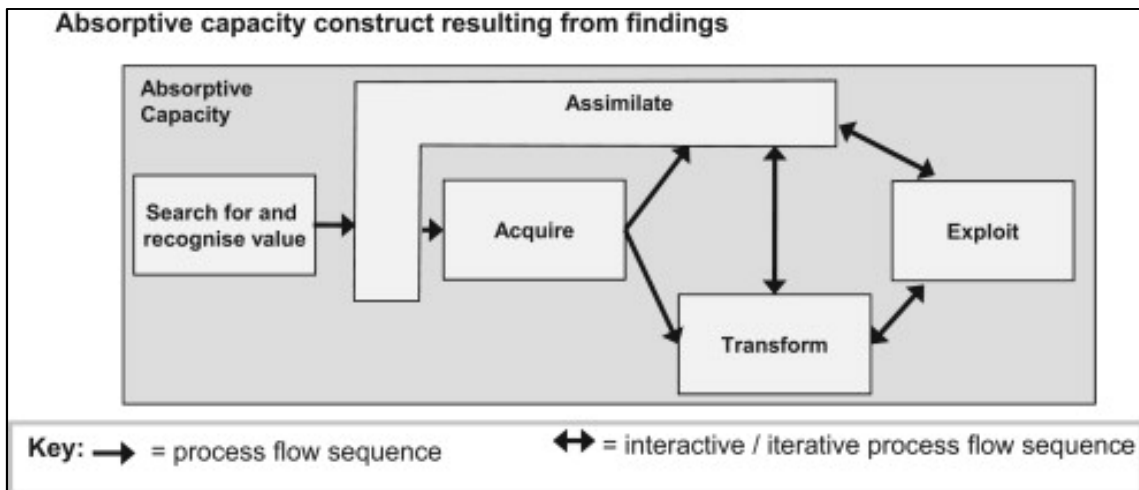


Figure 6: Patterson and Ambrosini's AC Model (2015, p.88).

For 'search for and recognise value,' the time duration is seen as a continuous activity. The AC constructs appear to take the time-ordered sequence of: (i) 'search for and recognise value' to (ii) 'assimilate' and then to (iii) 'acquire'. The key event is the identification of valuable intellectual property rights (IPR) in the external environment. This literal act of acquiring the legal rights to use the IPR orientates all other AC process constructs and associated activities. For the biotechnology firms in the Patterson and Ambrosini study, after they initially acquire and assimilate external knowledge there is *"continuous assimilating capabilities throughout the 'transform' and 'exploit' process components."* This continuous process is embedded in assimilating activities characterised by this industry sector.

They provide the primary logic for many of the co-development deals between biotechnology and pharmaceutical firms is for both sides to assimilate scientific, operational, regulatory or commercial capabilities from the other company (2015, p.84). In addition, assimilating information at any stage of the product development can require the use of external experts to clarify highly specific areas of science to fill knowledge gaps within the firm.

- This compels biopharmaceuticals firms to maintain a network of external experts to answer many ad hoc questions and gaps in expert knowledge.
- This also requires the firm to maintain the ability to interface with and assimilate that expert knowledge.

In a similar style of research to this study, Aribi and Dupouët's study (2016) of three large firms (over 500 employees) sheds further light on the non-linear process view of AC. The emerging non-linear

view of AC was initially raised by Todorova and Durisin (2007) and Volberda, et al., (2010) to suggest that a linear representation of AC is likely to be too simple and remote from the actual process. Aribi and Dupouët's study (2016) firstly confirmed that the absorptive process follows a sequence of exploration, transformation, and exploitation, as described by others (Cohen and Levinthal, 1990; Zahra and George, 2002; Lane et al, 2006; Todorova and Durisin, 2007). They identified feedback loops between the different phases of the process to extend the models of Zahra and George (2002), Lane, et al., (2006), and Todorova and Durisin (2007) which did not envision such loops, as shown in figure 7 below.

Secondly, Aribi and Dupouët (2016) identify a series of feedback loops within the main AC phases to extend Todorova and Durisin (2007) concepts by identifying a 'dialogue' between sub-phases not only in the transformation phase but also in the two others as well. Aribi and Dupouët' (2016, pp.23-24) results suggest AC displays several feedback loops, both within (intra) each main phase (*exploration, transformation, and exploitation*) and between (inter) each phase previously largely overlooked. With each phase, activities 'talk' to one another to add, enhance, or even suppress knowledge. These interactions continue until the decision maker deems the result satisfactory.

1. Loops within the main phases included:

- Loop in the exploration phase (AC 1) (between recognition and acquisition)
- Loop in the transformation phase (AC 3) (between assimilation and adaptation)
- Loop in the exploitation phase (AC 4) (between completion and application)

2. Loops between main phases included:

- Loop between transformation (AC 3) and exploration (AC 4)
- Loop between exploitation(AC 4) and transformation (AC 3)
- Loop between exploitation (AC 4) and exploration (AC 1)

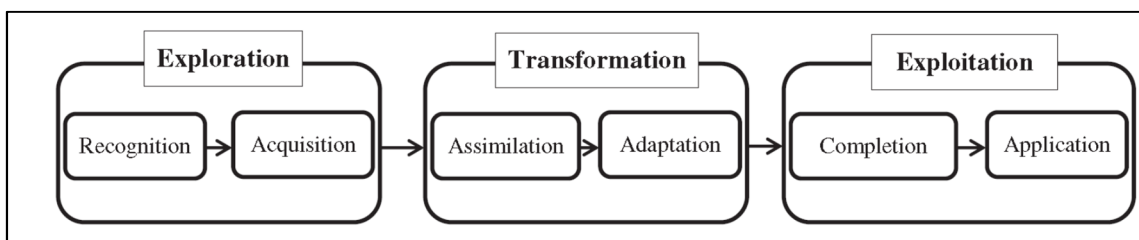


Figure 7: Aribi and Dupouët's (2016, p.16) AC Model with feedback loops*

*The different phases of AC (adapted from Lane et al, 2006, and Lichtenthaler, 2009). Note: Recognition corresponds to the introduction of new ideas; acquisition is the assessment and possible retention of these ideas; assimilation is new knowledge development; adaptation is modification of the existing knowledge base; completion is the finalization of new products; application is their introduction on the markets.

Aribi and Dupouët's (2016, p.24) AC model of organisational knowledge is grounded in practices and social interactions based of their previous work (Aribi & Dupouët, 2015). This describes more accurately a firm's AC and connects the construct to other important research streams, such as research on exploration and exploitation (organisational ambidexterity) and dynamic capabilities theory. Their model opens the way for further research on the non-linearity of AC. They describe a concept called 'irreversibility' in the process: firms never go back completely to a phase once it is finished; there are feedback loops between and within the main AC phases. This irreversibility is

embodied in the rules and systems followed by the firms' members and guarantees that the process will eventually come to an end, rather than becoming an endless loop. Irreversibility is thus probably not as important as previous models suggest; rather, it is important that firms maintain some degree of flexibility in the process. It seems that this flexibility is necessary to guarantee the alignment of the knowledge and product produced with the requirements of the other parts of the organisation as well as with outside partners and customers. It enables firms to avoid tunnel effects or overdue investments in a solution that would turn out to be a dead end (Aribi and Dupouët, 2016, pp.23-24).

A 'co-construction' phenomenon is said to take place in all three phases (Aribi and Dupouët, 2016); suggesting that a firm may engage in different routines across each AC phases in parallel with each other. This finding seems consistent with Todorova and Durisin (2007) who assert assimilation and transformation as two separate parallel elements. It also implies that the four dimensions of AC can be considered as parallel, as well as related to each other rather than just a discrete and linearly subsequent capacity (Todorova and Durisin, 2007). This view is echoed by Sciascia, et al. (2014) who argues that SMEs, with poor acquisition and assimilation of external knowledge, will have difficulties in successfully transforming the acquired knowledge to better address their needs. This is bound to imply some blurring and overlapping of the boundaries between assimilation and transformation (Todorova and Durisin, 2007) as well as between other dimensions of AC (Saad, Kumar, and Bradford, 2017, p.6919).



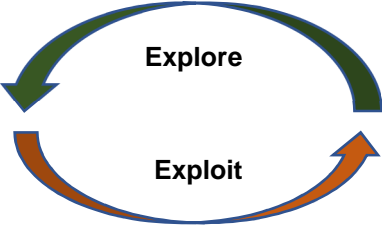
As the absorptive process unfolds, knowledge is progressively transformed (Nonaka, 1994). Two main dimensions are introduced for consideration:

- meeting the targeted market and/or needs of customers; and
- mastering the technology to serve that market/customer needs.

These two dimensions relate to either exploratory or exploitative innovation pursuits. Innovation is classified along two domains: *technological novelty and market novelty* (Abernathy and Clark, 1985; Jansen et al., 2006). Meeting the targeted market and/or needs of customers supports exploratory innovations to the market that are designed for emerging customers or markets; whilst mastering technology to serve that market/customer needs reflects exploitative innovations that address existing customer or market needs (Benner and Tushman, 2003; Danneels, 2002; Jansen, et al., 2009).

Within these two dimensions, knowledge evolves from uncertain and unrelated to certain and related (Turner and Makhija, 2006). As the absorption process unfolds, new knowledge is progressively enriched, and uncertainty is thereby reduced, and links between new and old knowledge are constructed; these two processes co-evolve with one another (Nonaka, 1994). Further, the process of uncertainty reduction and knowledge combination is not limited to the considered projects. It extends beyond the project and even the firm's boundaries. Not only must firms innovate but they must insert that innovation into their sets of competencies and into their broader environment. In this general process, firms display some idiosyncrasies due to the different kind of innovation pursued and the specificities of markets firms address (Aribi and Dupouët, 2016).

Table 5: Summary of Existing AC Models

Summary of Existing AC Models	
	<p>Acquire-Assimilate-Transformation-Exploit-Acquire (Linear Sequence – Zahra and George, 2002) AC 1 - AC 2 - AC 3 - AC 4</p>
	<p>(i) exploratory (recognise), (ii) transformative and (iii) exploitative learning (Lane, et al., 2006); AC1 - AC3 - AC4</p> <p style="text-align: center;">OR</p> <p>(i) acquisition, (ii) assimilation or transformation, and (iii) exploitation (Todorova and Durisin, 2007).</p> <p>AC 1- [AC 2 or AC 3] - AC 4; or more specifically being:</p> <ul style="list-style-type: none"> o Acquire - Assimilate - Exploit AC 1 - AC 2 - AC 4; or o Acquire - Transform - Exploit AC 1 - AC 3 - AC 4
	<p>Other derivatives can include:</p> <p>Acquire - Assimilate - Transform - Acquire - Assimilate - Exploit</p> <ul style="list-style-type: none"> o (AC 1- AC 2 - AC 3 - AC 1 - AC 2 - AC 4) <p>Acquire - Assimilate - Transform - Acquire - Assimilate - Transform - Exploit</p> <ul style="list-style-type: none"> o (AC 1 - AC 2 - AC 3 - AC 1 - AC 2 - AC 3 - AC 4) <p>Acquire - Transform - Acquire - Assimilate - Exploit</p> <ul style="list-style-type: none"> o (AC 1 - AC 3 - AC 1 - AC 2 - AC 4) <p>Acquire - Transform - Acquire - Assimilate - Transform - Exploit</p> <ul style="list-style-type: none"> o (AC 1 - AC 3 - AC 1 - AC 2 - AC 4 - AC 4) <p>Assimilate: can assume the acquired new knowledge is complementary to internal capacity to use to undertake final exploit phase and integrates with existing business routines without transformation processes or introducing new / deploying additional innovation capabilities.</p> <p style="text-align: center;">OR</p> <p>Transformation: can assume the acquired new knowledge is not easily assimilated into the organisation – either requiring more time to process or requiring the firm to develop and deploy new capabilities by additional expertise/information/knowledge. This will require or trigger the acquisition stage again to ensure assimilate any remaining knowledge deficiencies and complete the transformation process prior to deploying the exploitation stage.</p>

2.11 Antecedents of Absorptive Capacity

The 'dynamic capability' view of AC consists of a raft of internal and external antecedents that pertain to a firm's innovation performance and its effects. This study applies Volberda, Foss and Lyles (2010, p.941) integrated AC antecedents framework (shown in table 6) across both Potential and Realised AC (Zahra and George 2002) to provide method of analysis to the internal and external learning phases of the Zahra and George's (2002) AC model. The dominant and supporting antecedents across the four AC learning stages indicates the strength to the contributing effects to the development of a firm's AC as shown in table 7 below.

Table 6: AC Antecedents, Dimensions and Factors

AC Antecedents	Dimensions and Factors
1. Managerial (Dijksterhuis et al. 1999, Kogut and Zander 1992, Lenox and King 2004, Zahra and George 2002)	<ul style="list-style-type: none"> • Combinative capabilities • Management cognition/dominant logic • Individual knowledge development/sharing
2. Intra-organisational (Andersen and Foss 2005, Argote 1999, Van den Bosch et al. 1999)	<ul style="list-style-type: none"> • Organisational form • Incentive structures • Informal networks • Internal communication
3. Inter-organisational (Lane and Lubatkin 1998, Lane et al. 2001, Lyles and Salk 1986)	<ul style="list-style-type: none"> • Knowledge creation and sharing • Alliance management systems • Dyad and network knowledge development and transfer • Relatedness of organisations
4. Business Environmental conditions (Jansen et al. 2005, Van den Bosch et al. 1999)	<ul style="list-style-type: none"> • Competitiveness • Dynamism • Appropriability regime • Knowledge characteristics
5. Prior Knowledge (Cohen and Levinthal 1990, Lane et al. 2001)	<ul style="list-style-type: none"> • Depth of knowledge • Breadth of knowledge • Retrieval of knowledge • Short-term vs. long-term

Source: Volberda, Foss, and Lyle (2010, p.941)

Table 7: AC Learning Phases by Antecedent Types

AC Learning Phases	AC Antecedents				
	Intra-organisational	Inter-organisational	Prior related knowledge	Business environment conditions	Managerial conditions
AC 1 Acquire (External AC antecedent)	○	●	●	●	●
AC 2 Assimilate (Internal AC antecedent)	●	○	●	○	●
AC 3 Transform (Internal AC antecedent)	●	○	○	○	●
AC 4 Exploit (External AC antecedent)	○	●	○	●	●
● Dominant antecedent			○ Supporting antecedent		

Source: Author's compilation work based on Volberda, Foss, and Lyle (2010, p.941)

2.11.1 Potential AC

Potential AC, as discussed above, reflects knowledge acquisition and assimilation capabilities. It captures a firm's efforts to value, identify (recognise) acquire and assimilate new external knowledge. This is sometimes referred to as value creation in the literature and is focused on exploration process which refers to behaviours characterised by discovery, risk taking, and innovation activities. Exploration covers the notions of growth and adaptation (Venkatraman, 2006), structures, routines and leadership (O'Reilly and Tushman 2009; Ho, Fang and Lin, 2011).

AC 1: Acquisition

Acquisition refers to a firm's capability to identify and acquire externally generated knowledge that is critical to its operations and fundamental to their assimilation activities. A company's capacity to identify external knowledge is directly associated to its innovative capacity and, consequently, with its capacity to create new products. As more and better knowledge sources emerge, the greater is the possibility to exchange and combine knowledge associated with innovation. Acquisition of knowledge requires a firm to localise, recognise, and understand the importance of critical external knowledge for its business activity and operations (Lane and Lubatkin, 1998; Zahra and George, 2002). Hamel (1991) sees the acquisition of new, specialised scientific knowledge as a motivator for inter-organisational collaboration.

Acquiring new knowledge is seen as a motivation to engage in collaborative learning alliances (inter-organisational collaboration) for firms; and a generator of knowledge for an organisation (Expósito-Langa, Molina-Morales and Capó-Vicedo, 2011). The advantages to be gained from integrating and sharing knowledge between external parties include: the exchange of tacit knowledge; and opportunities for recombining knowledge into different combinations or used to inform other parties processing knowledge, where they would not ordinarily be exposed to without this two-way interaction. New knowledge sourced is critical to the firm's business activities especially when a firm seeks to strategically analyse the business environment. Strategic planning means controlling and analysing the environment to detect for opportunities and threats. This first dimension can be assimilated to the notion of 'competitive scanning' (Mcevily and Zaheer, 1999) or environmental scanning, which has been associated with the innovative capacity of the firm (Yigitcanlar et al., 2017).

External AC antecedents

Prior Knowledge, External Knowledge Networks and Inter-organisational Antecedents

Prior knowledge (Cohen and Levinthal, 1990), including investment in R&D, knowledge derived from recent scientific research (Zahra and George, 2002) and inter-organisational capacity to engage in collective (collaboration) learning is an important antecedent to a firm's acquisition capability. The capacity of knowledge identification is influenced by several factors such as:

- (i) depth of knowledge searches;
- (ii) breadth of knowledge searches;
- (iii) retrieval of knowledge; and

(iv) short-term-vs-long-term organisational knowledge memory.

In addition, other knowledge characteristics include different knowledge types contextual, declarative knowledge content or “know-what” (codified - explicit) such as common skills, knowledge bases, similar culture and similar cognitive structures, scholars have argued, enhance knowledge absorption and assimilation. Procedural knowledge - or the extent to which the knowledge consists of implicit and non-codifiable (tacit) skills or ‘know-how’ - is embedded in complex interactions, processes, and routines within the firm. Tacit knowledge is rendered ambiguous and consequently creates barriers to imitation (Kogut and Zander, 1992; Lam, 1997; Nonaka, 1994; Reed and De Fillippi, 1990; Simonin, 1999) and is difficult to transfer and absorb (Saviotti, 1998; Simonin, 1999; Szulanski, 1996). The third knowledge characteristic often examined is complexity. Knowledge complexity is defined as the number of interdependent technologies, routines, individuals, and resources linked to a particular knowledge or assets (Simonin, 1999). As knowledge becomes more complex, organisations need to absorb more areas of knowledge content, as well as understand the inter-linkages between the different content areas (Garud and Nayyar, 1994). Thus, simple knowledge is easier to absorb than complex knowledge.

While the above studies focus on knowledge characteristics that affect acquisition and assimilation, a few studies argue that the AC of a firm can be enhanced by increasing the *tacitness, complexity, and similarity component of its knowledge base*. For instance, developing routines that enhance recombining knowledge resources and knowledge complexity (Galunic and Rodan, 1998; Van den Bosch et al., 1999) enables a firm to recognize and assimilate more complex knowledge from external sources. Similarly, increasing familiarity through inter-organisational relationships and through belonging to a community increases an organisation’s AC (Beise and Stahl, 1999; Liebeskind et al 1996; McMillan et al 2000; Meyer-Krahmer and Meyer-Krahmer, 1998). This includes external micro business routines or ‘meta-routines’ such as identifying and recognising value of externally generated knowledge; learning from and with partners, suppliers, customers, competitors, and consultants and transferring knowledge back to the organisation.

These routines possess three attributes that have an influence on AC: intensity; speed; and direction. Intensity and speed determine quality in the acquisition capacity of a firm, direction affects the company’s lines of research to obtain external knowledge. A firm’s prior knowledge is important to this identification process to acquire knowledge, particularly from recent scientific R&D output. Inter-organisational learning antecedents help firms find prospective partners to learn from – or as simply put by Salk and Simonin (2011) as ‘collaborative learning’ alliances – to mean all types of organisational collaborations from equity joint ventures, to outsourcing, to cross-functional/cross organisational development teams. This research stream suggests that competitive advantage emanates from environmental learning and divides into two sub-streams: learning in dyadic and multiple relationships that requires consideration of knowledge creation and sharing; alliance management systems and relatedness of organisations.

A firm's external networks with other leading firms and local institutions can act as, *gatekeepers* between linking broader networks in a region. Adapting the work of social psychologist Kurt Lewin, Allen describes the '*technological gatekeeper*' or '*technology scout*' (external consultant or recruit) as '*individuals who occupy key positions in the communication network of the research laboratory; that is, those to whom others in the laboratory most frequently turn for technical advice and consultations*' (Allen, 1977, p. 13). Except in the case of one-person firms or very small organisations, an organisation's AC is not resident in any single individual, and it depends on the links across a mosaic of individual capabilities (Cohen and Levinthal 1990, p. 133). AC requires having porous boundaries, scanning broadly for new knowledge, and identifying and using those employees who serve as gatekeepers and boundary spanners (Volberda, 1996).

Cohen and Levinthal (1990) describe gatekeepers who act as 'boundary spanners' at the interface within and between a firm and its external environment. They argue that, if the expertise within the firm differs from external knowledge sources, the gatekeeper could improve a firm's AC through the collection and translation of relevant information. Schmidt (2010) confirmed that gatekeepers can translate information into a language understood by members of different departments and therefore foster internal knowledge sharing. He highlights the important role of a few key people for external information on its way to internal researchers. An important role in the communication of external knowledge is the boundary spanner who is involved in both internal and external communication networks. He or she connects the strengths of internal and external communication stars. Thus, gatekeepers can help to overcome barriers of external knowledge acquisition and internal knowledge sharing, that is the 'not invented here' syndrome (Katz and Allen, 1982).

AC 2: Assimilate

Assimilation refers to a firm's capacity to integrate external knowledge using business processes and routines that allow it to understand, analyse, process and interpret information obtained from external sources (Szulanski, 1996, Zahra and George, 2002). With low costs of transaction and communication, technological externalities can be exploited to establish positive feedback loops. In this context, routines of tacit and explicit knowledge and employee training as factors related to the assimilation capacity, which can be developed at a systems level. One of the critical points in the assimilation process is how to resolve inconsistency between new knowledge and existing knowledge bases (Yigitcanlar et al., 2017, p. 322).

Internal AC antecedents

Intra-organisational, Managerial and Business Conditions

Intra-organisation antecedents relate to the internal firm's culture, practices and routines adopted in business operations dedicated to carrying out multiple knowledge-related tasks, such as evaluating, assimilating, integrating, utilising, and building knowledge (Loasby, 1976). One of the critical points in the assimilation process is how to resolve inconsistency between new knowledge and existing knowledge bases. However, to gain all the added value potential of organisational knowledge, it is

not enough to adopt and exploit existing processes; it is also necessary to update knowledge bases. According to Nelson and Winter (1982), this assimilation process is highly influenced by the tacit knowledge of the company and internal factors. Others (Child, 1984) have emphasised diverse factors such as organisational structure, the degree of centralisation or the formalisation of tasks, responsibilities, power, and the allocation of decisions. For firms to benefit from this phase it requires learning processes based on contextual knowledge. A firm needs gatekeepers to act in the role of boundary spanners.

Contextual knowledge is mostly tacit and can be hidden from the activity where it is generated; in fact, it increases with activity and its temporary, social, and spatial contexts. This type of knowledge is difficult to describe even for the same agents involved, and hence it is also difficult to reproduce at a distance outside of the original context. In regional industrial areas and districts, tacit knowledge is relevant for communities of practice, that is, mutually mobile organisations using synergies in knowledge searching and learning processes in a cooperative context. External knowledge can be found in specific contexts, but in many cases is not understood and is responded to by people who are not involved in its generation. Consequently, it is difficult to assimilate this knowledge when firms do not have the internal routine practices and tools to do so (Teece, 1981) (Yigitcanlar et al., 2017).

Managerial antecedents include: (i) Combinative capabilities (coordination, systems, and socialisation capabilities); (ii) Management leadership and cognition/dominant logic; and (iii) Individual knowledge development/sharing. In line with Adner and Helfat (2003, p.1012), a dynamic managerial capability refers to the capacity of managers to create, extend, or modify the knowledge resource base of an organisation. Examples of these managerial capabilities and skills are the: structure of communication; the character and distribution of expertise; gatekeeping or boundary-spanning roles; cross-functional interfaces; and job rotation. Moreover, various formal and informal managerial incentives may differently influence AC and knowledge sharing. Aside from managerial capabilities and incentives, firm AC will be strongly influenced by cognitive processes on the managerial level and existing dominant logics of management teams (Mom, van den Bosch, & Volberda, 2009).

Business environment conditions refers to a firm's knowledge environmental conditions (Jansen et al. 2005, Van den Bosch et al. 1999) to include: (i) *competitiveness (competitive advantage)*; (ii) *dynamism*; (iii) *appropriability regime*; and (iv) *knowledge characteristics* (Volberda, et al; 2010, p.942). When the knowledge environment is turbulent, firms tend to develop AC aimed at exploration, with low efficiency, a broad scope, and much flexibility. When the knowledge environment is stable, firms tend to develop AC aimed at exploitation, with high efficiency, a narrow scope, and little flexibility (Van den Bosch, et al.,1999). These ideas, although interesting, are illustrated with case studies only and need to be tested in a large-N context. Also, the moderating effect of various contextual factors (competitiveness, dynamism, knowledge characteristics) and regimes of appropriability on the relationship between antecedents, AC, and performance requires more

research (Lichtenthaler, 2009). Cohen and Levinthal (1990) show negative moderating effects of appropriability on the relationship between antecedents and AC, implying that AC increases with weak regimes and competitive knowledge spillovers. Zahra and George (2002), however, propose positive moderating effects between AC and performance because strong regimes help to sustain competitive advantage (Volberda, et al; 2010, p. 942).

2.11.2 Realised AC

Realised AC (exploitation learning phase) reflects knowledge transformation and commercial application. It represents the firm's ability to integrate and reconfigure the existing internal knowledge and the newly assimilated knowledge. Exploitation refers to behaviours characterised by implementation, production, selection and refinement (March 1991; He and Wong 2004). Transformation is also affected by inter-organisational factors such as incentive systems, organisational structures, leadership and governance (Hotho, Becker-Ritterspach, and Saka-Helmhout 2012; Fornasiero and Zangiacomini 2013; Rangus and Slavec 2017). The successful exploitation of knowledge is also associated with the adoption of a long-term and prolonged process of investment and knowledge accumulation (Greve, Engelen, and Brettel, 2009) rather than a short-term and unstructured way to learning that many SMEs seem to embrace (Bozbura, 2007).

AC 3: Transformation

Transformation is a firm's capability to develop and refine the routines that facilitate combining existing knowledge and the newly acquired and assimilated knowledge. This goal can be achieved by the addition or suppression of knowledge, or the reinterpretation of existing knowledge. It requires two fundamental elements: *internalisation and conversion*. Zahra and George (2002) suggest that an indicator of a firm's degree of success in transformation could be the number of ideas or research projects centred on new products. Camisón and Forés (2010, p.709) even extend that perspective on transformative learning as *"...the internal routines that facilitate the transference and combination of previous knowledge with the newly acquired or assimilated knowledge. Transformation may be achieved by adding or eliminating knowledge or by interpreting and combining existing knowledge in a different, innovative way."* Transformational learning processes are underpinned by internal AC antecedents and involve an intricate renewal of existing organisational knowledge stocks and abilities to re-combine with new knowledge acquired.

AC 4: Exploitation

Exploitation is a firm's capacity to competitively use new external knowledge to achieve its organisational goals (Lane and Lubatkin, 1998). Routines create an environment that allows firms to refine, extend and leverage existing competencies and routines, or develop new ones. and make more efficient existing activities, or to create new ones, by means of incorporating the identified and analysed new knowledge for the firm's activities (Tiemessen, et al., 1997) and business operations (Zahra and George, 2002). This learning process is underpinned by external AC antecedents that provide the means to internalise previous knowledge to obtain new products, processes, abilities, or

new firm organisation (Spender, 1996). At this phase, the exchanges and combinations of knowledge resources require some specific conditions and capacities related to the use of new knowledge. Consequently, high-quality information is required and the capacity to share and cooperate becomes extremely important. In the regional industrial literature, emphasis is placed on the fact that regional locations must contribute to sustain the innovative capacity of firms and favour the adoption of innovations.

2.12 Organisational Ambidexterity

Firms are increasingly compelled to enhance or sustain their competitive advantage by exploiting existing and exploring new knowledge for innovation (Jansen, et al., 2006). The notion of organisational ambidexterity (Tushman and O'Reilly, 1996) is a crucial concept in research on organisations (Raisch, Birkinshaw, Probst, & Tushman, 2009). Ambidextrous firms gain sustainable competitive advantage by exploiting existing knowledge while simultaneously exploring new knowledge and exploiting opportunities (March, 1991; Levinthal and March, 1993). Exploration and exploitation are viewed as distinct innovation strategies (Enkel and Heil, 2014; March, 1991). Exploratory innovation is more distant from firm logic than exploitative innovation (Jansen et al., 2006) and hence the assumption is that embryonic exploratory ideas from external sources require more assimilation efforts than embryonic exploitative ideas from external sources.

External knowledge that is assimilated by a firm requires additional individual efforts to facilitate its use. Due to the 'not invented here' (NIH) syndrome (Katz and Allen, 1982), it is particularly difficult to use an idea when it is derived from external sources (West and Bogers, 2014). Furthermore, if externally derived knowledge conflicts with established working modes, individual efforts to utilize it may be crucial (da Mota Pedrosa et al., 2013). In contrast, individual efforts to utilize external knowledge may have little impact on innovation that is in line with existing working modes. Many studies have highlighted the need for organisations to develop ambidexterity (e.g., Chen and Kannan-Narasimhan, 2015; Enkel and Heil, 2014; Raisch et al., 2009; Wei et al., 2014). Ambidextrous organisations can synchronise exploration and exploitation and thus simultaneously pursue exploratory and exploitative innovation (Jansen, et al., 2008; Li, 2013). Organisational ambidexterity not only supports firms in overcoming structural inertia resulting from a focus on exploitation, but also prevents them from fostering exploration without gaining benefits from it (Jansen et al., 2008; Levinthal and March, 1993).

More recently, the notion of ambidexterity was introduced to capture the ability to pursue two disparate strategies at the same time, such as pursuing incremental and discontinuous innovations and change (O'Reilly and Tushman 2008, 2013; Atuahene-Gima 2005; Judge and Blocker 2008); or achieving flexibility and efficiency; or pursuing differentiation and low cost (Porter 1980). Swift (2015) adds that when firms successfully transition between R&D based exploration and exploitation activities they benefit from practicing 'sequential ambidexterity' and were in general, superior performers. A firm that does not manage this, or infrequently manages this outcome, will have

incomplete or partial Potential AC, unable to handle external knowledge and poor firm performance (Flatten, Greve, & Brettel, 2011, p. 147). Flatten, et al. (2011, pp.147-148) find that SMEs with a well-developed AC – they note older firms have a relative advantage here – can additionally use it as an instrument to improve the effectiveness of strategic alliances, and thus enhance firm performance. Size of the firm did not make any significant to performance, which suggests that the efficiency of an alliance depends largely on the operational members of the alliance: the members of both partners form a new learning unit, and it is up to them to transfer the acquired external knowledge into their respective organisations and to manage the conversion from individual to organisational.

Chesbrough (2003) revitalised the idea of collaborative innovation, which has as its most prominent objective the combination of collaboration partners' distinctive yet complementary knowledge to strengthen internal knowledge bases in a value adding way. Therefore, a growing body of literature stresses the importance of inter-firm (inter-organisational) ambidexterity described as firms that are capable of simultaneously pursuing exploitation and exploration through collaborative innovation (Raisch et al., 2009). This rationale provides the foundation for the view that firms access knowledge from sources outside their boundaries to create value for both exploitative and exploratory innovation activities (Koza and Lewin, 1998). Several studies have substantiated the potential of inter-firm ambidexterity to balance exploitative and exploratory innovation with in separate collaborations to reduce the inherent tensions of resource allocation (Holmqvist,2004; Lavie and Rosenkopf, 2006; Rothaermel and Deeds, 2004).

Firms focusing on acquisition and assimilation of new external knowledge (i.e., Potential AC) can continually renew their knowledge stock, but they may suffer from the costs of acquisition without gaining benefits from exploitation. Conversely, firms focusing on transformation and exploitation (Realised AC) may achieve short-term profits through exploitation but can fall into a 'competency trap' (Ahuja and Lampert, 2001, Mudambi and Swift 2011, and Swift, 2015) if unable to respond to external environmental turbulence. To avoid the competency trap a firm needs to incorporate this transformed knowledge into its systems, processes, routines and operations (Lichtenthaler, 2016). It must not only refine existing knowledge and competences but also to create new operations and competences. The application of these dimensions allows for the development of new knowledge within firms through collaboration with external R&D networks, such as universities.

Firms that change their R&D spending, in either direction, have experienced higher incidences of firm failure, decline and mortality. Firms that generate earnings performance (profit) more frequently and extensively relative to their competition are less likely to fail following a compact, significant decrease in R&D spending. Firms that substantially reduce R&D spending to improve earnings, particularly when firms move from exploratory to exploitative R&D, tend to hollow out the core competency in the firm, which can significantly increase the chance of failure. A firm's long-term performance can be improved by adopting balanced exploration-exploitation orientations depending on the environment they face. Firms characterised by incremental change benefit more from the

learning effects of maintaining ambidexterity, which lead to superior performance. Firms in discontinuous change contexts, however, suffer more from the misalignment that reinforcement creates, which affects their performance negatively (Luger, Raisch, & Schimmer, 2018).

AC does require more than just R&D spending/financial investment. Due to its multi-dimensional nature, it makes for a complex process and requires different combinations of knowledge (Lane, et al; 2006;) that can be complementary or substitutive (Hagedoorn & Wang, 2012), along with an understanding of different characteristics of knowledge, organisations and partner types (Lichtenthaler, 2016, p.666) associated with collaborative . Collaboration with external sources of knowledge is a complex and challenging task for SMEs, in which customer requirements are rapidly changing and the lifecycles of new products are increasingly shorter (Lichtenthaler, 2016). It requires SMEs to overcome barriers and obstacles with the use of knowledge from external sources and an ability to exploit it commercially. This ability is significant in high technology branches since technologies are changing so rapidly that small technology firms specialising in the production of high-technology products must match or exceed the pace of change to maintain competitiveness (Kozmetzky, et al; 2004).

2.13 Innovation Systems and External Knowledge Source Partners

To understand the diverse networks of external knowledge sources, firms need to consider: the source and type of knowledge they require; the breadth and depth of their existing networks; and how integrated or 'central' they are in relation to regional, national and global networks (Tsai, 2001). The external network of regional SMEs can contribute to its high performance (Huggins and Johnston (2009 and 2010), Huggins and Thompson (2015 and 2014)). The role of knowledge is critical to the innovation processes. Entrepreneurial SMEs are firms that engage in deliberate innovation activities to seek a competitive advantage in the market which contributes to a wider range of entrepreneurial discovery functions. Increasingly, product innovation is a co-creation process, adding value between different participants of the supply chain such as supply producers, customers, competitors or suppliers. The key ingredient is the collaborative learning and their actions within this network of participants of its supply and value chains the firms create. These network exchanges improve with reliability and trust, which requires frequent face to face interactions and exchanges. This makes the nature of knowledge both an interactive and social phenomenon. The role of tacit knowledge and the 'doing, using and interacting' (DU&I) research mode of knowledge creation is highly valuable. The role and nature of external networks of knowledge source relates to issue of proximity, which pertains to concepts of social network theory (Gilsing 2005, pp. 25-26).

More specifically, research attention has been directed to accounts of why some regional areas are more successful than others in developing and implementing continuous improvements of their knowledge bases and network structures (Cappellin, 2009, p.157 in Cappellin and Wink), as well as analyses of growing inequalities of sustainable activity, development and growth between metropolitan and non-metropolitan regions. SMEs rely on external sources of knowledge for R&D

and other innovative activities, and this has predominantly been from customers, competitors and suppliers in the system. In the case of many SMEs, universities and research institutions tend to be the lowest source of external knowledge. The firm will anticipate the application of acquired knowledge will be adopted or assimilated without major transformation of the internal business operations and routines.

The acquisition of new knowledge – in the form of tangible items such as standard digital technology, equipment and machinery – requires lower order learning competencies relating to operational routines. This form of knowledge will not contribute to radical innovations and is therefore limited to lower order forms of innovation outcomes. In contrast, external knowledge inflows from ‘science-based’ actors influence innovation indirectly, via AC, and therefore require assimilation and or transformation phases to make sense of the new knowledge to the business. Largely, for new knowledge to create economic value, a level of interpretation and re-interpretation is required to produce unanticipated outcomes through the NPD process.

This is consistent with AC theory that suggests firms derive innovation benefits from new external knowledge only if they recognise its value, internalise, and exploit it (Cohen and Levinthal, 1990; Zahra and George, 2002). Corral de Zubielqui, et al., (2016) suggest that there is a need to delineate external knowledge flows by specific actors, as the circumstances in which AC transforms external knowledge inflows into innovation are not universal or guaranteed, in line with recent work (Moilanen, et al., 2014). They reveal that external knowledge inflows from science-based actors are positively associated with AC, in line with Moilanen, et al.’s (2014) findings. Finally, Corral de Zubielqui, et al., (2016) results reveal that AC has a two-fold effect:

- (i) a positive direct effect on innovation outcomes; and
- (ii) an indirect effect on firm performance through innovation, consistent with theoretical expectations (Cohen and Levinthal, 1989; Zahra and George, 2002) and some empirical evidence (Kostopoulos, et al., 2011).

These results, together with the indirect effect of knowledge inflows from science-based actors on innovation via AC, underline the importance of AC to innovation outcomes and ultimately, firm performance (Corral de Zubielqui, et al., 2016, pp.18-19). Innovation networks are a specific mode of this arrangement. The emergency of knowledge flows and networks are explained not by transactions costs considerations, but by strategic relational capacity interests, the wish for knowledge ‘appropriability’, and realising the synergetic effects resulting from technological and a balance of knowledge similarity and dissimilarity (usually operationalised as complementary resources or capabilities) (Freeman, 1991, p.512).

Jones and Corral de Zubielqui (2017, p.264) highlights the literature that examines the role of prior research on networks and open science, in particularly the increasing importance of sourcing knowledge from external organisations such as universities in particular (Cohen et al., 2002; Hansen

and Klewitz, 2012; Perkmann et al., 2011; Perkmann and Walsh, 2007; Powell and Grodal, 2005); however empirical evidence of the impact of direct links between universities and firms is weak and inconsistent (Bekkers and Freitas, 2008; Dornbusch and Neuhäusler, 2015), including in the sustainability oriented innovation SME context (Klewitz, 2015). Fernández-Esquinas et al. (2015) noted that the difficulty in translating scientific results into the market is well established, raising important questions with respect to how to maximise benefits from universities and related research institutes for skills and development (OECD, 2007), especially in peripheral regions in which the industrial fabric is composed of many SMEs with low absorptive capacity (Fernández-Esquinas et al., 2015).

2.14 Industry-University Innovation Collaborations

Recent research that investigates the relationship between a firm's AC and use of external sources of knowledge have struggled to definitively determine which external knowledge source contributes more towards a firm's innovation performance and outcomes (Corral de Zubielqui, et al., 2015). Moreover, specifically, research has defined the extent to which this performance can be attributed to a firm's AC (Corral de Zubielqui, et al., (2016) – the later study shows external knowledge sourced from scientific actors, indirectly affects innovation performance only through a firm's AC. In addition to this mediation effect, AC capacity has a positive direct effect on innovation, and an effect on firm performance through innovation. The relationship between the different pathways SMEs take to source external knowledge, such as universities, and the extent to which these pathways affect SMEs' innovativeness is examined by Corral de Zubielqui, et al., (2015 and 2016). The relationship between the use of different sources of external knowledge and innovation performance is not proportional to how frequent SMEs access and acquire knowledge from different external sources. Whilst universities are generally the least frequently sourced external knowledge partner used by SMEs, the effects upon a firm's innovation performance is greater than other more frequently used knowledge source partners – specifically on the condition that a firm has a high level of AC.

Bishop, D'Este and Neely (2011) survey of industry-university collaborations in the UK identified a firms' R&D commitments, geographical proximity, and the research quality of university partners have a distinct impact on the different types of benefits from interactions with universities. Recently, industry and universities collaboration has been examined from several different perspectives. The results show that benefits from interactions with universities are multi-faceted, including enhancement of the firm's explorative and exploitative capabilities. We find geographical proximity is crucial for assessing problem-solving as an important benefit, while interactions with top quality universities have a positive influence on the benefits associated with firms' downstream activities (Bishop, et al., 2011).

The role of universities in building regional innovation systems (RISs) has been studied by Caniëls and van den Bosch (2010). The role of AC to enhance an understanding of knowledge university knowledge transfers to the wider regional knowledge system offers opportunities for increased

regional innovation and commercialisation. This has been examined in context of a quadruple helix innovation system by Miller, McAdam, Moffett, Alexander and Puthusserry (2016). Kirchberger and Pohl (2016) reviewed current literature on technology commercialisation where newly developed technologies are integrated into products which sell successfully to the market. The study focused on the different interaction channels through which technology commercialisation occurs. They analysed the main groups of institutions, which could either act as developers of technologies and/or organisations bringing these technologies to the market – namely universities and research institutes, technology start-ups, and established companies.

The explanation for this marginal impact of universities is strongly connected to the nature of the 'knowledge exploitation' sub-system or entrepreneurial ecosystem within the Scottish innovation system. In the literature, the role of universities as an external knowledge source to firms, such as SMEs, is presented as part of the 'triple' and emerging 'quadruple helix' regional innovation system and the commercialisation of knowledge transfers from universities. This is discussed in context of the 'third mission' of universities and the extent which universities can contribute to regional economic development. Overall, however, the review of the literature suggests a strong policy disconnect between research produced in universities, and the innovation needs of local entrepreneurial actors. Low levels of entrepreneurship, weak AC in SMEs, and an inability to engage within complex technologies, all combine to prevent local technological spillovers. Therefore, the explanation for the marginal impact of universities is strongly connected to the nature of the 'knowledge exploitation' sub-system or entrepreneurial ecosystem. Once again, this disconnect suggests the importance of detailed studies of local context to draw out qualitative insights into the factors that might promote successful collaborations between universities and SMEs.

Universities play an important role as places of higher learning, training, education and research to generate new knowledge production. Research into the role of industry-university collaborations discusses its contributions beyond that of general academic knowledge generation to one of assisting economic development, business development and commercialisation ventures (Dutta and Hora, 2017) through the innovation process. The application of knowledge generated at universities and public research institutes to the industrial innovation process has been identified as a key mechanism for economic growth (Romer, 1990). At the same time, a highly-skilled, university-educated workforce is necessary for the successful transfer, absorption, and adaptation of knowledge in new contexts (Schiller and Diez, 2010, p.275). The capacity of university research to help industry identify solutions to specific technical needs and problems – particularly SMEs that have limited internal R&D development capacity – is perceived as one of the key benefits to industry-university collaborations. Despite these broader benefits to economic development evidence is still limited to clearly demonstrate the role of universities to improve industry innovation performance and outcomes.

2.15 Universities role to contribute to Regional Economic Development

The role of a University to economic development beyond that of providing a skilled and educated workforce is increasingly being viewed in terms of its contribution towards both industry and individual firm innovation performance and outcomes. The nature of a university's innovation capacity to collaborate and exchange new knowledge with industry raises a raft of other considerations worthy of investigation, beyond that of its traditional roles of education, teaching and undertaking academic knowledge generation research. Universities' new role in this area is sometimes referred to as the 'third mission' (Rothaermel, et al; 2007; Link and Scott 2010), or discussed via similar notions such as the 'triple helix effect', triple helix systems of innovation (Ranga & Etzkowitz, 2013) and the emergence of 'quadruple helix' relationships (McAdam, Miller, & McAdam, 2018). They include licensing of patents, corporate partnerships, and the creation of spin-off companies (del Campo, et al; 1999; Fini, et al; 2010; Kroll and Liefner, 2008). Universities and research institutes directly affect the stock of intangible knowledge assets within a region. Knowledge is not only the most important input required for research and teaching, but also forms the most important output of these activities.

The role of research and development activities pursued by universities shows that localised knowledge is embedded in regional university capacity by such factors as key scientific personnel (star scientists). Similarly, Este and Patel (2007) show that universities in the UK interact with firms using a wide variety of channels, although they interact more frequently through consultancy and contract research, joint research or training relative to patenting or spin-out activities. Schiller and Diez (2010, pp.275-276) examined qualitative data acquired from interviews with distinguished German scientists. It was found that the excellence of star scientists manifests itself in several ways. However, their results do not confirm the expectation that knowledge flows are predominantly locally embedded. The impact on the local economy was especially low for industrial collaborations. As such, there can be a mismatch between what a regional university can offer, in comparison to local industry needs, future industrial development opportunities, and scientific and technological discoveries. Individual characteristics of researchers (e.g. previous collaborative research experience and academic status such as a Professor) were found to have a stronger impact than the characteristics of their departments (i.e. research quality) or universities in explaining the variety and frequency of interactions (Corral de Zubielqui, et al., 2015 p. 438). Considering the 'sticky' or tacit nature of knowledge, the physical presence and proximity between industry and university researchers has supported the role of proximity to the innovation process, particularly social interactions and exchanges required for collaboration.

The effects of physical proximity to industry-university collaborations and its frequency as a specific mechanism of knowledge and technology exchanges depend on different factors, of which geographical proximity has received particular attention. Geographical proximity is important to enable staff from both firms and a university to interact and help create and transfer tacit knowledge. When firms and universities collaborate it also involves relationships with other organisations, which extends proximity considerations to include other dimensions such as institutional and social

networks across the innovation system (Boschma, 2005). Ponds, Oort, and Frenken (2007) provide at least two reasons to explain why geography is important for industry-university research collaborations:

- Firstly, collaborations across great distances remain more expensive than collaboration at closer range, despite improved transportation possibilities and the rise of the information and communication technology; and
- Secondly, collaboration is assumed advantaged by physical proximity, especially in science-based technologies.

2.16 Role of a Firm's AC and University Collaborations

A Swedish study revealed that the benefits from university cooperation are conditional upon the firm's level of AC (Biedenbach, Marell and Vanyushyn, 2018). Firms with low levels of AC that engage with universities tend not to achieve any noticeable increase in innovative output – an effect even more pronounced for firms operating in sectors characterised by low technology, R&D, and knowledge levels (Biedenbach, et al., 2018, p.81). In contrast, a firm with higher levels of AC can benefit from collaborating with a university, as shown by studies of the moderating effects of AC on a firm's innovation competencies in industry-university collaborations (Kobarg, Stumpf-Wollersheim, & Welppe, 2017). A firm's AC capacity shapes its demand for knowledge and technology transfer because firms with low AC depend more on local high-quality universities (Laursen, et al., 2011) for industrial research, as well as for the expertise and training that are offered to the local market for skilled labour. This later acts as a medium for the diffusion of academic knowledge spillovers (Beise and Stahl, 1999) which may particularly benefit SMEs with a lower capacity to compete in the national labour market (Maietta, 2015, p. 1342).

Research shows there is a divide between the innovative requirements of regional businesses and the types of research being conducted at regional research-intensive universities. Some observers highlight the lack of AC which limits the ability of SMEs to utilise the advanced levels of research being undertaken within their region (Roper, et al. 2006; Pinto, Fernandez-Esquinas, and Uyarra 2015 in Brown, 2016, pp.197-199). In this scenario, SMEs may search new knowledge locally and more broadly wherever it may be found as relevant to its needs. Likewise, a university's research focus may not align with the knowledge needs of the region's economy, and the university will seek to use and expand its expertise further afield to achieve research aspirations and academic outcomes. This mismatch manifests in several ways, particularly in in less developed regions (Brown, 2016; Pelkonen and Nieminen, 2016).

Brown (2016) for example highlights the systemic weaknesses within the local entrepreneurial ecosystem of the Scottish regional innovation system, which include the way in which Scottish SMEs obtain their 'inbound' sources of innovation (Brown, Gregson, and Mason 2015; Brown and Mason, 2014). Rather than using formal relationships with universities or other R&D providers, SMEs increasingly rely much more heavily on 'open innovation' sources such as collaborations with peers,

suppliers, customers and end users (Brunswicker and Van de Vrande, 2015). Knowledge-intensive business services (KIBS), such as consultants and private research organisations, play a key role in providing knowledge to SMEs (Tether and Tajar, 2008), especially in less favoured regions (Pinto, Fernandez-Esquinas, and Uyarra, 2015 in Brown, 2016, pp.197-199). Interaction of Scottish firms with universities is thus not a major source of innovation.

In 2009, 55 percent of Scottish businesses were 'innovation active' and, of these, only 13.5 percent (14.8 percent for the whole UK) co-operated with universities – and only around 10 percent viewed universities as 'medium-to high' in terms of level of importance for their innovation sources and requirements. This picture is consistent with earlier studies of Northern Britain using European CIS data (Freel, 2006, Freel and Harrison, 2006). Smaller firms can be averse to formal contracting with third-party organisations such as universities due to their perceived inefficiencies and the associated costs of these formal relationships (Brown and Mason, 2014). Intriguingly, despite this clear preference for utilising knowledge sources from these 'open sources' of innovation (e.g. such as customers, suppliers and peers etc.) rather than universities, the latter is the route many policy interventions try to foster (Brown, 2016). The figures for Scotland and the UK can be compared to a limited number of similar style studies in Australia to include the sparsely populated region of the Australian State of Tasmania and the city region of metropolitan Adelaide, the capital city of another sparsely populated Australian State of South Australia.

Tasmania is a very small and sparsely populated Australian State with about 520 000 residents. It has had high unemployment rates, and its population and economic growth rates are relatively low in comparison to mainland Australia. A 2014 report compiled by the Australian Innovation Research Centre (AIRC) indicated the share of all Tasmanian businesses with five or more full-time employees that were innovative has remained relatively stable: 78 percent were innovative in the 2010 and 76 percent were innovative in the 2013 Innovation Census. In 2013 37 percent of innovating firms fell within the largest firm size category (250 or more FTEs), followed by 26 percent of firms with 100-249 employees. Of those businesses that innovate most are either simple 'technology adopters' (14.3 percent) or 'modifiers' (74.4 percent), with their innovations limited to modifying technologies or ideas acquired from other businesses. The remaining 103 firms (11.3 percent) were considered highly innovative or 'innovation leaders'.²

The 2013 Innovation Census included a survey of 1 204 responding firms that were innovative or had incomplete or abandoned innovations, 81 percent sought knowledge or assistance for innovation from at least one type of external knowledge partner source. The most commonly reported source of knowledge was suppliers (57 percent of firms), followed by customers (47 percent), and industry or trade associations (44 percent). Less frequently cited sources were business consultants or

² Innovation leaders are businesses that conducted in-house R&D in the 3 years to June 2013 & developed highly novel product or process innovations. They introduced new to market products as well as selling products on international markets, and/or introduced a new to world process innovation.

commercial labs (38 percent), government departments or agencies (23 percent), and universities or the CSIRO (12 percent). Of the innovative leaders 32 percent (33 firms) of them sourced knowledge from universities or the CSIRO and the majority (75 percent) had less than 49 full time employees (ARIC, 2014, pp. 15, 17-18). The study by Corral de Zubielqui, Jones, Seet, Lindsay (2015) of SMEs in the Adelaide greater metropolitan area show similar results similar to both the Scottish/UK and Tasmanian figures.

The greater metropolitan city region of Adelaide in Australia has a population of over 1.3 million people with a mixed history of economic growth and prosperity that struggles with both employment and population growth. Corral de Zubielqui, et al., (2015) reveals figures for SMEs showing a significant increase in the proportion of SMEs innovating with business size: 58, 67, 80 and 88 percent cent of sole-traders, micro, small and medium enterprises, respectively, innovate – an average of 78 percent (excluding sole traders). Similarly to the 2013 results for Tasmania innovating firms in Adelaide tend to be associated with size – however an inverse relation exists; larger the size the few numbers of innovative firms. It was found that size did matter when it comes to use of universities as a source of external knowledge. A number of control variables were considered. Only the logarithm of firm size showed any sign of being statistically significant – in the case of small firms, the incidence rate ratio (IRR) is \ln , so size is inversely related to log size. The only evidence is that, all other things equal, size is associated with less innovation (Corral de Zubielqui, et al., 2015, p.450).

In terms of the four major innovation types (product, process, organisational and/or marketing) SMEs are most likely to implement two or more types of innovation. In terms of the proportion of innovative SMEs that collaborate with other organisations, and their geographic locations. Innovative SMEs (micro, small and medium size) are least likely to collaborate with universities and private non-profit and commercial R&D enterprises: 10 percent or less of SMEs in each size category collaborates with universities; 7 percent or less partner with commercial laboratories/R&D enterprises; and 5 percent or less collaborate with private not-for-profit research institutions. However, when SMEs do collaborate with universities, it is more likely to occur within Australia than internationally. SMEs are most likely to collaborate with clients/customers or suppliers, with almost 50 percent or more of SMEs collaborating with clients/customers or suppliers in Australia. Suppliers, followed by clients/customers, and other parts of the wider organisation, are also the most frequently used overseas partners. Taken together, these results indicate that SMEs collaborate with organisations other than universities and related R&D enterprises for knowledge access.

SMEs are most likely to use research results published by these institutions (12 percent) and employ new graduates (9 percent) in Australia. However, the proportion of SMEs accessing knowledge using these channels is modest with 17 and 27 percent of small enterprises and medium enterprises, respectively, employed new graduates, and 11 and 14 percent, respectively, used university-published research. Innovative SMEs in the sample are least likely to use patents, designs or other IP rights from institutions, or employ academic or research staff (3 percent each). Specifically, only 1 percent of small enterprises use IP rights. Medium enterprises are also unlikely to utilise IP rights

(8 percent) but are significantly more likely than small and micro enterprises ($p_{0.05}$). Medium enterprises are least likely to contract R&D from these institutions (6 percent); medium and small enterprises are more likely than micro enterprises to employ new graduates; medium enterprises are also significantly more likely than small enterprises to employ consultants from universities (13 and 3 percent, respectively), and significantly more likely than small and micro enterprises to employ academic or research staff (13 and 2 percent, respectively; $p_{0.05}$) (Corral de Zubielqui, et al., 2015 p.447).

Corral de Zubielqui, et al., (2015, p.445 & p.452) results show that collaboration occurs as part of existing business-to-business (B2B) relationships, specifically with customers and suppliers which are part of the SME's supply chain, even if these customers and suppliers are overseas. They explain their results are an indication that SMEs collaborate with supply chain members in Australia and internationally, but are unlikely to collaborate with universities, which suggests that SMEs collaborate with organisationally closed enterprises (Davenport, 2005; Knoblen and Oerlemans, 2006), irrespective of the geographic location. This phenomenon may also be explained by the role of social network ties in the knowledge transfer process, whereby both '*instrumental and expressive ties*' are needed to facilitate trust and knowledge transfer (Zhou et al., 2010). Despite universities being important centres of innovation, SMEs will form instrumental ties with universities, which require less trust; as HEIs and SMEs are seen to operate in very different sectors and with very different practices (Manev and Stevenson, 2001). In contrast, SMEs will tend to form expressive ties with those organisations within their supply chain and/or value chain firms create, as the interactions between them are more likely to be longer-lasting, more frequent and thereby requiring a higher level of trust, even in the context of industries that face rapid technological change and that are required to innovate rapidly (Pérez-Luño, et al., 2011).

2.17 Type of University Knowledge, Collaboration and Innovation Performance

SMEs that form collaborative arrangements with universities to expand their technological capacity can access the existing facilities, expertise, and research staff of a university. The nature of this relationship could be a simple informal transaction, exploiting the services of a public funded research organisation, like a knowledge intensive business (Pinto, Fernandez-Esquinas and Uyarra, 2015, Johnstone and Huggins, 2016). Sengupta and Ray (2017) adopt the following definition to distinguish between two categories of knowledge exchange between industry and universities:

- the research commercialisation channel – to include formal indirect contact through the use, patents, licensing, and creation of university spin outs, etc; and
- academic engagement channels – to include more formal tacit direct contract research, collaborative research and consultancies.

Pinto, et al., (2015) reveals how SMEs' internal ability and prior knowledge base enable them to connect and interactive with universities under a variety of different type of collaborative networks, such as alliances and partnerships. Such networks can occur in formal and informal ways to nurture

the creation, sharing and exchange of knowledge between university researchers and industry. One benefit from a range of collaborative networks includes supporting a firm's AC, namely a firm's explorative and exploitative capabilities. The benefits of more formal arrangements can be found in developing alliances and partnerships for a range of research projects, to support new knowledge creation for potential industrial application and commercial gain. As such a university can offer both problem-solving capabilities to meet shorter timeframes and the more immediate research and knowledge needs of industry, whilst also offering future, 'frontier' research opportunities. Industry-university collaboration research (Corral de Zubielqui, et al., 2015 and 2017) applies the classification of university knowledge types presented in the tables below where the type of knowledge interaction reflects the degree of formalisation. Knowledge type is classified using formalisation, personal contact and transfer of tacit knowledge in line with prior work (Schartinger, et al., 2002 in Corral de Zubielqui, et al., 2015 and 2017)).

The various ways in which publicly funded research may potentially benefit industry, and which comprise what is commonly referred to as:

- knowledge/technology transfer links that include the use of scientific publications and university-generated intellectual property (IP) (e.g., patenting, licensing, commercialisation) ; and
- human mobility mechanisms aimed at transferring skills (e.g., graduate recruitment and postgraduate education/vocational training of employees).

These links are generally considered to have low relational (generic links) involvement or engagement since they do not necessarily require relationships between universities and industry users (Perkmann and Walsh, 2007). In contrast, industry-university relationships refer to situations where individuals and/or groups from academia and industry work together on specific projects and produce common outputs and are characterised by high relational (relational links) involvement. Examples include research partnerships (e.g., collaborative or sponsored research) and research services (e.g., academic consulting, contract research and use of research facilities).

Medium size firms (with 20-199 employees) generally recorded higher levels of knowledge sourced from universities to outperform smaller firms (5-19 employees) and the balance types (less than 5 employees). The data suggests that while, overall, SMEs in different size categories rely on generic university-industry links rather than pathways with high relational involvement, medium sized enterprises are more likely than smaller firms to access knowledge via relationship pathways, and specifically, medium enterprises are more likely to employ consultants and university academic and research staff. Finally, the statistically significant results produced by Corral de Z et al., (2015, p.452) showed that university-industry knowledge access pathways are a more important factor in explaining innovativeness – generic knowledge links are more likely to decrease rather than increase innovativeness, relational-based mechanisms increase innovativeness.

Table 8: Industry-University interactions - Generic and Relational Links

Type of interaction	Mechanism	Description
Generic links	Human resource transfer/mobility	<ul style="list-style-type: none"> • Cooperation in the education of graduate students • Vocational training for employees • Employed new graduate (s)
	Scientific publications	<ul style="list-style-type: none"> • Used research results published by these Institutions
	IP	<ul style="list-style-type: none"> • Used patents, designs, or other IP initially for these Institutions
	Informal sources of ideas	<ul style="list-style-type: none"> • Sources of ideas from universities and other institutions
Relational links	Research services	<ul style="list-style-type: none"> • Used research facilities of these Institutions • Contracted out research and development to these institutions • Contracted academic or research staff
	Research partnership	<ul style="list-style-type: none"> • Collaborative research

Source: Jones and Corral de Zubielqui (2017)

The findings of the 2015 study is substantiated further in Jones and Corral de Zubielqui (2017) to give further credence to the authors 2015 study and reinforces the strength firms have with use of generic knowledge links with university research and the relatively weaker use of relational knowledge links when it comes to innovation performance outcomes. They investigated the role and effect of university-firm interactions on innovation outcomes, and firm performance in sustainability-oriented innovation from a data sample of 153 Australian SMEs. They revealed, 88 percent of SMEs [which have sustainability as a key driver of innovation] undertake at least one type of innovation (product, process, organisational and/or marketing). Enterprises are most likely to utilise generic links with universities to access knowledge with more than half of the enterprises sourcing ideas informally (57 percent), while around one third or more of SMEs use human resource transfer mechanisms (i.e. 39 percent employ new graduates, 32 percent cooperate in the education of graduate students and 43 percent provide vocational training to employees).

Similar proportions (36 percent) of enterprises also use research results published by universities (Jones and Corral de Zubielqui, 2017, p.276). Their study also revealed that, between one fifth and one third of 'Sustainable Oriented Innovative' (SOI) SMEs access knowledge through relational links, with the use of research partnerships, research facilities and contracting out R&D to universities. Whilst generic knowledge is well sourced from universities and enhances innovation performance the relational knowledge developed through closer collaborations with universities is a much poorer in comparison.

Table 9: Knowledge access pathways between SMEs and Universities

University-SME knowledge access pathways	Personal interaction precondition for transferring tacit knowledge	Formalisation of the interaction	Transfer of tacit knowledge	
Employed academic or research staff	Yes	Yes	Yes	Relational
Used consultants from these institutions	Yes	Yes	Yes/No	
Contracted out research and development to these institutions	Yes	Yes	Yes/No	
Employed new graduate(s)	No	Yes/No	Yes	Generic
Used research results published by these institutions	No	No	No	
Used patents, designs, or other intellectual property rights initially from these institutions	No	Yes	No	
Used research facilities of these institutions	No	Yes	No	
Source: Scharinger, et al., (2002) in Corral de Zubielqui, et al., (2015)				

2.18 Conceptual Theoretical Framework

This study explores the learning dimensions of five firms whilst collaborating with Deakin University across the exploratory and exploitative stages of an organisation's AC through the NPD process. Buganza, et al., (2014) observed that the relationships between SMEs and universities vary across three core phases of the NPD process and split their approach to working with universities; either they only perform testing activities together or they collaborate throughout the entire NPD process. SMEs engage in collaborations with universities following a progressive model; from simple collaboration projects such as the initial testing phase to more complex collaborations during the last project commercialisation phase. In so doing SMEs establish a trust-based relationship with universities. Both technology and project management capabilities are critical requirements to manage complex forms of collaboration across the entire NPD process (Buganza, et al., 2014, p.69).

Huang, Soutar, and Brown (2002) noted that SMEs are mainly focused on production or technical phases such as product development, preliminary production analysis, in-house product testing, and preliminary technical analysis. The literature has shown that collaborations with universities can be beneficial in all three phases (Lee, 2000; Santoro and Chakrabarti, 2002) but research has not focused on how SMEs could establish collaborations with universities during the different phases. Buganza, et al., (2014, p.72) adopts a simplified NPD process composed of three distinct phases:

1. Applied research – the set of activities associated with accessing and using the knowledge, methods and techniques of the scientific community for a specific, commercial, or client-driven purpose;
2. Prototype Development – the actual design and development of the product, resulting in the final design and prototype; and
3. Testing and Commercialisation – the set of activities devoted to testing product performance and fine-tuning products before the market launch and large-scale manufacturing production.

Recently, the literature provides a remarkable attempt to understand the impact of NPD projects' characteristics on the formation of first-time NPD networks (Badir and O'Connor 2015). These scholars investigate the micro-level of analysis and identify the relevance of knowledge in an NPD project, considered the main determinant of effective sourcing decisions. Galati and Bigliardi (2017) takes a knowledge-based view of the firm (Grant, 1996) to the debate and examined not only the formation of first-time NPD partnerships from a knowledge perspective, but also the case of NPD partnerships with well-known players, thus limiting the role of trust.

The foundation to a firm's innovation capability to develop new products involves several businesses processes and micro organisational routines. Many SMEs rely on acquiring necessary knowledge from an external source that makes AC an important business competency. The research explores the notion that AC is critical to:

- innovation and growth, which is associated with the capabilities of SMEs to explore and exploit knowledge and technology from an external source such as a university; and
- a firm's innovation capabilities that are underpinned by a variety of organisational antecedents (Volberda, Foss, and Lyles, 2010) relating to organisational learning, knowledge management, and collaborative processes;

to achieve competitive performance, business adaption, growth and employment creation, amongst other identified socio-economic benefits.

The AC literature examines the 'micro-economic' routine behaviours of individual economic participants within a region in terms of location choices, productive and innovative capacity, competitiveness, and relations (collaborative networks, etc.) with the local system and the rest of the world (Capello, 2011, p.11). Understanding how new knowledge derives from places of R&D like a university and then processed by firms' capabilities (such as business innovation routines) to derive commercial gain from innovation outcomes at specific regional locations by such firms is crucial in understanding how regions innovate and contribute to economic growth and development (Capello, 2013, p.187).

As previously discussed, the research literature adopts a variety of different definitions for several critical concepts that can be ambiguous and conflicting. This study bridges what the relevant literature defines as antecedents or precursor factors to a firm's AC, and innovation outcomes of that can be attributed to a firm's AC. Antecedents provide an explanation to understanding AC in terms

of innovation capabilities as shown in the table below assembled from the referenced sources. In this study, a firm's innovation capabilities are a combination of the interactive exchanges of innovation activity that bridge [connect] the process of the exploration – exploitation dichotomy. The focus for this project is to examine the 'innovation competency' of SMEs abilities to deploy innovation activities, [either with or without in-house R&D capacity, such as dedicated R&D staff and/or limited R&D finance], which benefit from collaborating with a university on NPD.

Lewin, et al. (2011, pp. 87-90) refer to meta-routines as higher-level routines that define the general, abstract purpose of routines and that are expressed by practiced routines, which are firm specific, idiosyncratic, and observable. Because practiced routines can be organisationally idiosyncratic, highly contextual, and tacit, they may not coincide with widely accepted and standard managerial practices. The examples of practiced routines (shown in the tables below) vary along many dimensions, from tacit norms to explicit rules, programs, or even managerial practices. Although seemingly unrelated, they share a common purpose underlying the corresponding meta-routine. The variety of examples of practiced routines observed in the literature reflects the high variety of how organisations can achieve the purpose of the meta-routines. In other words, although the practiced routines are highly idiosyncratic, the taxonomy of AC meta-routines can be generalised across firms.

Moreover, because of complementarities that may not exist in certain organisations, because of learning effects and because of the heterogeneity between individual members of organisations, practiced routines vary in terms of both predictability of outcome and effectiveness for developing AC, and so it may not be possible to predict the exact performance outcomes of similar individual practiced routines implemented in different organisations.

Feldman and Pentland (2003) and Pentland and Feldman (2005) refer to the ostensive and performative levels to indicate, respectively, the abstract and narrative aspect of routines and the specific actions of routines, which are context specific and specific to the people who execute them. They noted that the two levels do not necessarily coincide. This distinction reveals some similarities with our notion of meta-routines and practiced routines in the sense that meta-routines are theoretical and abstract components of AC capabilities, and practiced routines are their expression within organisation. However, we posit that there is not a direct correspondence between meta-routines and practiced routines, because practiced routines may correspond to multiple purposes defined by different meta-routines. This aspect is developed further in the discussion section (Lewin, et al., 2011, pp. 87-90)

The taxonomy of meta-routines identified by Lewin, et al., (2011) make up the organisational internal and external AC capabilities. The provided examples of practiced routines illustrate the expression of each meta-routine within organisations that underlie the configuration of firms' AC capabilities. It is expected that the variation across configurations of AC capabilities will be reflected in firms' innovation performance. The enacted configuration is likely to vary along two dimensions: the actual routines that are being implemented and the extent to which interdependencies and

complementarities are achieved. Together, these factors determine whether organisations achieve AC capabilities consistent for being innovators or imitators, as reflected in their innovation performance, e.g., timing, rate of change viewed in terms of incremental or disruptive radical innovation.

The research seeks to make the AC concept operational through the adoption of the following empirical approaches of referenced literature below.

1. The use of AC antecedents by (Volberda et al., 2010)) as the 'given' or adopted set of organising antecedents of AC.
2. The use of Flatten, et al; (2011a) and Gebauer, Worch, and Truffer (2012) as the framework for data coding and data analysis of the AC dimensions developed by Zahra and George (2002) to formulate key learning processes of AC.
3. The innovation capabilities are derived from data analysis of firm's AC as induced from the interpretation of the case study data. These capabilities show how AC mediates a firm's innovation performance is one of the key questions to be answered. These capabilities are micro-foundations or the internal and external business practice meta-routines - as per Lewin, Massini and Peeters, (2011, figure 1 p.87 and figure 2, p.90) as shown in the tables 10 and 11 below.

Table 10: Internal Innovation Capabilities - AC Meta-Routine practices

Meta AC routines (Intra-organisational antecedents)	Examples of internal AC-practiced routines
1. Facilitating variation	<ul style="list-style-type: none"> • Solicitation of scientists and engineers to propose and pursue innovative ideas (15 percent time unaccounted for at 3M, Inside Out initiative at Analogue Devices, Non-traditional Innovations at Baxter International, Research Exploratory Program at IBM,30 start-up teams selected annually at Hewlett-Packard, rotating council of peers to select exploratory projects at Xerox) • Open office plan chosen to foster informal interactions (IDEO) • Technology Forum and Technical Council (3M) • Brainstorming sessions organised to bring together persons with different technical or market knowledge (IDEO)
2. Managing internal selection regimes	<ul style="list-style-type: none"> • Shared sense of PC ecology boundaries to determine projects to be funded (Intel) • Seeking market signals ("make a little sell a little"; 3M) • Development of prototypes that perform at least as well as what is available on the market (IDEO) • Autonomy of middle management to support and allocate resources to projects outside CEO's vision (Rotemberg and Saloner 2000)
3. Sharing knowledge and superior practices across the organisation	<ul style="list-style-type: none"> • Central provision of information on value of specific new practices and on their implementation: <i>brochures, liaisons between corporate groups, BU, and facilities</i> (Lenox and King,2004), and company-wide e-mails and newsletters (Emerson) • IT-based knowledge codification system to store and manage knowledge, and retrieve it for future needs (3M) • Visit of other company's divisions (Jansen, et al., 2005) • Cross-functional project teams (Freeman ,1987)
4. Reflecting, updating, and replicating	<ul style="list-style-type: none"> • Problemistic and local search (Cyert and March 1953) • Learning from good and bad experience (Banc One) • Learning from managing alliances (Zollo and Winter 2002)

	<ul style="list-style-type: none"> • Learning programs (in-house and external training) to increase the knowledge base of the company (Daghfous 2004, Minbaeva et al. 2003) • “Copy exact” principle to leverage optimisation of processes across units (Szulanski 2000; Intel)
5. Managing adaptive tension	<ul style="list-style-type: none"> • Internal rate of change greater than external rate of change (GE) • One and two comparison benchmark (GE)/Comparison to industry best in class as opposed to industry average (Massini et al. 2005) • Stretch goals—Big Hairy Audacious Goals (Collins and Porras 1997)

Table 11: External Innovation Capabilities - AC Meta-Routine practices

Meta AC routines Inter-organisational antecedents	Examples of external AC-practiced routines
1. Identifying and recognising value of externally generated knowledge	<ul style="list-style-type: none"> • ‘Gatekeepers’ (Cohen and Levinthal 1990) • Probing (Brown and Eisenhardt 1998) • Mining patent literature (Cohen et al. 2002) and industry trade magazines (IDEO) • Market research, end user surveys, Informal interactions with industry actors (Kohli et al. 1993)
2. Learning from and with partners, suppliers, customers, competitors, and consultants	<ul style="list-style-type: none"> • Co-development relationships (Dyer and Singh 1998, Koza and Lewin 1998) • Collaborating with “lead users” (von Hippel 1984,1986) • Collaborating with suppliers (Cisco) • R&D partnerships (Tether 2002) • Networking with outside organisations, universities, and research institutions in particular (Koch and Strotmann 2008) • Unfiltered information from key clients to CEO (Cisco) • Open source (e.g., innocentive.com) • Occupying leadership roles in standard setting industry organisations (Rosenkopf et al. 2001)
3. Transferring knowledge back to the organisation	<ul style="list-style-type: none"> • Sharing within company knowledge acquired in inter-firm relations (Rosenkopf et al. 2001) • Pacing the partner (Koza and Lewin 1998)

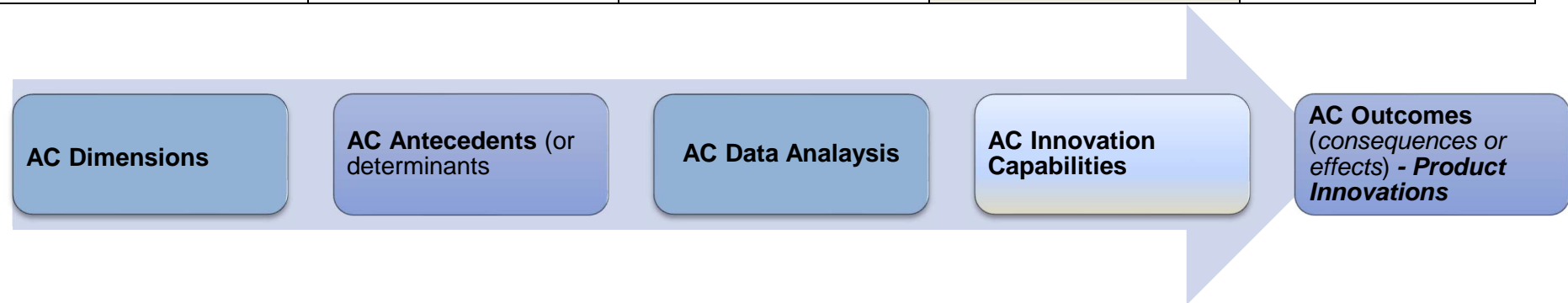
4. Outcomes of AC (new product developments – production innovation (incremental and radical) may include a patent issued by firm or finished final product launched to the market or supplied to a customer, such as a global OEM.

5. Key Findings and Conclusions to include statement response to the research questions, limitations of the study and recommendations for future research.

This last step links the research findings to research question, aim and objectives. The use of noteworthy quotations from the transcript to highlight major themes within findings and possible contradictions is one technique adopted. The responses of research participants to the interview questions provides numerous statements that can be related to the data coding structure and assists with providing meaning to the responses. The meaning created is predominantly derived from an informal or inductive form of analysis of the remarks of each participant as captured in the interviews conducted; this for the most part forms the qualitative research findings presented in the paper.

Table 12: Conceptual Literature Framework

AC Dimensions	AC Antecedents	AC Data Analysis Framework	AC Innovation Capabilities to how AC mediates a firm's innovation performance	AC Outcomes – Innovation Performance Product Innovations
AC as identified by Zahra and George (2002) <ul style="list-style-type: none"> • AC1 - Acquire • AC2 - Assimilate • AC3 - Transform • AC4 - Exploit 	Antecedents of AC as identified by <ol style="list-style-type: none"> 1. Volberda, Foss and Lyles (2010) 'An integrative Framework of Absorptive Capacity' and includes <ul style="list-style-type: none"> • Prior related knowledge • Managerial conditions • Intra-organisational • Inter-organisational • Business environment conditions 	<ol style="list-style-type: none"> 1. Flatten, Engelen, Zahra and Brettel, (2011); 2. Gebauer, Worch, and Truffer, (2012) 3. Noblet, Simon and Parent (2015). 4. Pierre and Fernandez, (2018). 	To be answered Micro-foundations or internal and external business practice routines as innovation capabilities – as per <ol style="list-style-type: none"> 1. Lewin, Massini and Peeters, (2011) and 2. Teece, 2007. 	Product Innovation derived through the New product development (NPD) process to include the following categories <ul style="list-style-type: none"> • New to a firm • New to a firm's market or • New to the world market product innovation



3 CHAPTER THREE: RESEARCH METHODOLOGY

This chapter discusses the research philosophy and design methods used in the study. As discussed in earlier chapters, the research seeks to provide some new insights to how SMEs innovate through the lens of the AC concept. This study of AC takes an empirical exploratory approach, grounded in the knowledge-based view (Grant, 1996) of the firm, to highlight innovation capabilities as a specific firm dynamic capability (Teece, et al., 1997; Teece, 2007; Teece, 2017). This method draws on insights from several disciplines, such as Evolutionary Economics, Organisational Learning and Knowledge Management, Economic Geography, and Regional Economic Development, adapting these insights for use with a qualitative case study that combines documentary analysis, interviews and observational techniques.

The use of qualitative case methods in technology transfer research is increasing, but there currently is no overarching review of qualitative case study methods on technology transfer research. In the field of entrepreneurship and small business, a study by Henry and Foss (2015) found a limited number of studies that use qualitative case methods, and suggest that this method has been applied across a variety of contexts such as family businesses, entrepreneurial networking, and innovation. Few papers published in entrepreneurship journals use qualitative case methods, suggesting that this research method is not fully established within entrepreneurship scholarship. Some have argued, however, for a greater acceptance of the use of case methods (Cunningham, Menter, & Young, 2017, p.925). Qualitative case studies specifically provide a deep and rich source of information that can effectively give more in depth and exploratory accounts of business activity. Case study method can also be combined with the use of traditional quantitative statistical analysis currently widespread in innovation studies, to provide for a mixed method approach in future research.

3.1 Research Philosophy

The research ontology of this study views knowledge constructed in social contexts that continuously evolves, providing both a public and private good that creates economic value. This economic value includes both tangible and intangible assets used in the innovation process. This view is underpinned by a constructivist perspective that the reality of knowledge can develop common social meanings and perceptions. The study aligns with the 'interpretivist' perspective and views innovation as a phenomenon socially constructed from selected participants' experiences, interactions with other people in terms of their position or role within place. This creates a set of 'norms' being routines, rules (formal and informal), levels of trust, and barriers such as nepotism and path dependency, all which can unduly impact on the innovation process.

Such cultural practices or 'mindsets' are further informed by a range of factors such as the nature, duration, frequency, and density of relationships and ties between individuals and groups and the role of 'centrality' within network theory (Tsai, 2001). From the institutional perspective, the business environment consists of networks of learning as part of the innovation process. Constructivism can

adopt an 'interpretivism' epistemology that perceives knowledge of social phenomena is created from perceptions and actions of those social actors concerned with their existence. Formally, constructionism can be defined as "*ontological position which asserts that social phenomena and their meanings are continually being accomplished by social actors*" (Bryman, 2016, p.23). Consistent with this perspective is that the participants interact within a broader innovation system. Due to differences and being sufficiently heterogeneous to allow for diversity and variety a process of combing and re-combing existing and diverse parts of knowledge occurs.

Knowledge is also subjective; constructed socially by the cultural practices of different individuals, groups, and institutions. Cognitive activities necessarily imply social interactions and discursive co-construction of knowledge (Aribi and Dupouët, 2016, p.16). New knowledge is often built from existing or prior knowledge and provides the basis for the development of organisational memory in SMEs (Van Wijk, Van Den Bosch and Volberda, 2011, p.273; Desouza and Awazu, 2006, p.35). Through this view knowledge is seen as emerging from practice and social interactions (Brown and Duguid, 2000; Tsoukas and Chia, 2002; Amin and Cohendet, 2004 in Aribi and Dupouët, 2016, p.16). Organisational knowledge is acquired, shared, and applied predominantly through the social practices of its members (Nahapiet and Ghoshal, 1998; Adler and Kwon, 2002 2004 in Aribi and Dupouët, 2016, p.16). Hence, social interactions are critical to any cognitive activities, including knowledge absorption. As AC is considered an organisational capability that consists of a set of business learning processes and routines, these routines are so close to action that they cannot be separated from acting or practicing. Thus, as Regnér (2008, p. 568) notes, researchers need to link AC to "*...individual-level and group-level activities and interaction if we are to understand their origins, the way they change over time, and the underlying social (and possibly causal) processes and mechanisms.*"

This study takes a practice-based view considered to be useful to capture AC empirically, which is not new in empirical research. Cook and Brown (1999, pp. 386-387) point out that the epistemology of practice can show "*...the co-ordinated activities of individuals and groups in doing their 'real work' as it is informed by a particular organisational or group context*". Marabelli and Newell (2014, p.1) from a research philosophy discuss the knowledge (possessed) and knowing (practice) epistemologies which they consider are recursive, mutually constituted and complementary. A practice-based perspective provides an alternative approach for the analysis of absorption routines, one that provides the researcher with a comprehensive picture of what the members of an organisation do and how organisations work (Duchek, 2013, pp.322-323). This poses challenges for researchers, because they may have to reconstruct the practice of many different stories. In this context, Pentland and Feldman (2008) remark facetiously "*...identifying a particular routine is a bit like trying to isolate the Gulf Stream from the Atlantic Ocean*" (in Duchek, 2013, p.323).

Knowledge acquisition, transfer, and its recombination can be carried out in a linear way because knowledge is passed on and transformed pretty much in the way a physical asset would be classically conceptualised. However, knowledge is increasingly viewed in a non-linear way as an 'epistemology

of practice' (Cook and Brown, 1999). Any cognitive activity – acquisition of knowledge, transfer of knowledge, creation of knowledge – is situated in physical and social contexts that enable and shape it. Terms such 'learning systems' involving multiple people both at the individual and organisation level within a place that forms collaborative interactions to create a 'learning region' within a wider innovation system framework. This learning is subject to cognitive functions such as information processing capabilities, which can be limited, costly and hence never perfect (Gilsing, 2005, pp. 2-3).

The innovation system is never static but is dynamic; it changes and evolves, as new knowledge emerges from prior knowledge and technology. Depending on the cognitive distance (Nooteboom, 2000) between parts of the innovation system, achieving complete mutual synergy and understanding of the various parts will allow for diversity of knowledge that yields potential Schumpeterian 'creative gales of destruction'. At the firm-level, there can be different types and levels of inter-firm interactions, which generate different networks, learning patterns and outcomes (Gilsing, 2005, p.3). The issue of frequency also relates to notions of proximity and density of network ties (weak / thin and/or dense / sparse) and concept of achieving the right balance or the notion coined 'optimal cognitive distance' (Nooteboom, 2009, p.100). Adopting the cognitive theory of the firm (Nooteboom, 2009) extends the use of the term innovation competence for a firm to demonstrate a range of dynamic innovation capabilities. These potential abilities can maximise the cost of forming (appropriating) new knowledge and undertaking innovation, to increase commercial returns and economic value of the new intellectual property.

In economics the notion of optimal cognitive distance implies an inverse (inverted) U-shape effect of accumulating sufficient knowledge and innovation performance. In the ongoing pursuit of knowledge and learning, the optimal amount will be achieved by a range of antecedents conducive to both intra and inter-organisational collaborations of networks across geography. As a firm pursues different innovation pathways, a greater or higher cognitive distance is required between its rival firms, which require ventures further afield and contingent on its AC (de Jong & Freel, 2010, p. 48). This stimulates the creation of new levels of learning, inquiry and research to form new knowledge. Nooteboom (2009, p.107) describes the 'boredom effect' contributing to a crowded space that decreases the returns to knowledge. The more one knows, the more one must seek out exotic, distance sources of knowledge to learning something new and novel. This effect, when applied to combinations within a firm, has implications for limits to the size of a firm, in decreasing returns to the range of capabilities (2009, pp.107-108).

3.2 Qualitative Research Methodology

The conceptual theoretical framework developed from the literature reflects a cognitive learning process informed by a dynamic capability (Teece, et al; 1997) perspective of a firm's AC. This involves examining the role of different antecedents (factors) as determinants of innovation, which is a complex and context-bound organisational issue. This study takes an inductive approach and does

not involve formulation of hypotheses. An inductive approach can contribute to new theories and generalisations. It starts with a research question/s, aims and objectives to derive findings from the collected data and its analysis, to provide valid answers at the end of the research process. The research question/s is derived from a research inquiry into the antecedents of AC to SMEs innovation competency and the development of 'dynamic' innovation capabilities.

The coding structure adopted measures derived from empirical research (Gebauer, et al., 2012, p.63) that identifies, or attributes, specific learning processes deployed by business to represent explicit procedures and routines, or meta-routines of a firm's AC. The data analysis involved coding of the transcribed interview text inductively, applying the coding structure. The unstructured interviews did not explicitly follow the codes as an interview question script. The questions posed to participants instead explored the AC learning processes to allow for individual narratives to form and explore through the course of each interview. As such, richer raw data was extracted to resonate with different individuals involved with the collaborations from both the firms and university perspectives.

Case studies, particularly explanatory style cases, are ideal to answer how and why questions, often about a contemporary set of events, over which the investigator has little or no control (Yin, 2003, pp.6 and 9). Yin (2003) notes one observer states that 'the essence of a case study, the central tendency among all types of case study, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result' (Schramm, 1971 in Yin, 2003, p.12). "*The case study method explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information...and reports a case description and case themes*" (Creswell, 2013, p.97).

The relevance of innovation systems theory is discussed in context of the specific role and interactions between firms and a university, as a sub-set of participants ('actors') in the wider knowledge production network. This system orchestrates multiple participants, between sources of new knowledge and users, such as industry, which need a variety of external knowledge sources to produce commercial innovations. The dynamics of this interaction is instrumental to a region's innovation capacity and the innovation competency of SMEs role to create economic value to new knowledge. This sample of SMEs value research and development in terms of investment and participation (financial, personal and time) with a medium-term future horizon to create an economic competitive business/enterprise base, to meet new markets, match client requirements in terms of product specifications and ultimately introduce *new to world market* or *new to a firm's market* products.

The SMEs seek product differentiation from engaging with the innovation process, and a commitment to unique high-quality innovations in their respective business product lines and markets. The SMEs selected have a history of having both either a strong manufacturing and industry experience; strong

academic and applied technical research backgrounds; and/or have developed personal contacts, confidence and trust with academic staff from Deakin and allied associates such as CSIRO. Deakin University staff and allied researchers from CSIRO have developed a high level of competence in the specific scientific areas of polymer fibres, textiles, advanced material and composites science. Such partnerships could have not been developed without the initial presence of CSIRO in Geelong. The original CSIRO research presence in the region stems from its early pioneering days of Wool fibre research at an older facility in Belmont, an industrial suburb of Geelong.

As part of this hub there is regular interaction between the firms and university staff. In some cases, this involves direct involvement of a firm's internal capacity – namely R&D staff employed by the firm, which undertakes their own internal R&D and other non-R&D activities across their organisation. Their ability to do this relies on their dynamic capabilities revealed by the interviews and case study. This case study of a small cluster of SMEs provides evidence of the emerging network ties to the region through R&D collaboration with the University. It further provides evidence that such firms not only value the knowledge that is created with a university, but also, that universities can be an important source of external knowledge – that industry can use and exploit for new production development and innovation products.

3.3 Proposed Case Study

The case study is a multiple embedded unit analysis of five SMEs collaborating with Deakin University. Most of these SMEs have formalised their collaborative partnerships in an Australian Research Council (ARC) funded Industrial Transformation Hub. This hub is an initiative which strives to accelerate the transformation of the Australian manufacturing industry by developing novel fibre technologies to facilitate more sustainable, advanced manufacturing of fibre materials and products that will impact on significant global issues, including reducing our environmental footprint and improving public health and wellbeing.

The Hub received \$4.7 million funding from the ARC as part of its Industrial Transformation Research Hub scheme. Further contributions from partners have given the Hub a total value of \$13.2 million over five years. Led by Deakin University, the Hub contains three research Programs, centred on nano short-fibres, advanced carbon fibres and high value-added applications. It brings together five industrial partners, of which four are discussed in this thesis. They are joined by experts from Swinburne University of Technology, CSIRO and six international higher education institutions.

The most popular qualitative research methods include interviews, case studies, document analysis, studies, observation, focus and questionnaires with open ended-questions. Interviews provide a method to collecting data through oral quiz using a set of pre-planned questions that can be structured, semi-structured or unstructured questions. The main advantages identified of interviews (Genise, 2002; Shneiderman and Plaisant, 2005) include:

- direct contact with the users often leads to specific, constructive suggestions;
- they are good at obtaining detailed information; and
- only a few participants are needed to gather rich and detailed data.

The study adopted an open interview style, with unstructured conversations framed by the AC literature. Several attempts to develop structure and semi-structured scripted questions led to the decision to use the unstructured style to give respondents freedom to speak without too much guidance. This methodological decision enabled participants to determine what was most important to analyse, which enabled the data better to express individual and organisational memory. While unstructured interviews can pose problems for hypothesis-testing they are particularly well suited for exploratory investigations that are attempting to gain insight into complex phenomena in which independent variables cannot easily be isolated. One drawback, however, is the greater difficulty of standardising information provided by different participants, since each interview takes on its own format (Preece, Rogers, and Sharp, 2002). This study compensated for this potential problem through a structured coding process to make comparisons possible.

Unstructured interviews can be vulnerable to bias and comparison of answers given by different respondents tends to be difficult due to the differences in formulation of questions. At the same time, unstructured interview techniques provide exceptional flexibility over the direction of the interview, for both the interviewee and interviewer. This flexibility allows for robustness in matching the data to the participants' experiences, their role in the organisation and to some extent personal beliefs and views. The level of questioning can vary suit to match the context allowing participants to be quizzed more deeply on specific issues as they arise. In exploratory research, this level of flexibility is particularly valuable for achieving the goals of the research. The interview questions for this study were therefore not 'set in concrete' but were also not developed to privilege any specific outcome, other than to reflect the core research questions. In saying this, data analysis proved a time consuming and difficult task to ensure that the diverse data collected in unstructured form, could be structured at the point of data analysis.

3.4 Phase 1: Background Data and Literature Review

The research was conducted in multiple, iterative phases. Phase 1 encompassed the initial project scope and preparation of the research proposal, including an extensive review of the relevant literature on the innovation process, the contribution of innovation to regional economic development, the role of SMEs, regional innovation systems and knowledge production. More specifically the literature review focuses on the role of the AC construct to the innovation competency of individual firms and its contribution to regional innovation capacity. Statistical data studied included collections of economic data from the OECD, ABS and other Australian government reports on innovation, regional economic development and the knowledge economy were examined through the course of the project.

3.5 Phase 2 Qualitative Data Collection Methods

3.5.1 Overview of Interviews

The data collected during the fieldwork process consists of both primary and secondary sources of data. Unstructured interviews conducted with research participants forms the primary data collected. Study participants included senior management from the firms, five research staff associated with Deakin University's **Institute for Frontier Materials (IFM)** and several other stakeholders from the University, Carbon Nexus and the Innovative Manufacturing CRC, see table 13 below. Recruitment methods are discussed in the next section. An ethics application was submitted and approved by RMIT College Human Ethics Advisory Network (CHEAN) College of Design and Social Context on the 9th February 2016 being Project number: CHEAN B 0000019695-10/15.

All interviews were audio recorded, and then transcribed. All interviews were conducted over a period between November 2016 and July 2017 and were conducted either face to face on the premises of the respective participants workplace. All participants received a copy of the interview transcript and further information was sought directly from participants as required to clarify specific details via emails. The interviews took the form of unstructured conversations, loosely organised around the four AC learning phases, but primarily focused on participants' explanations, in their own words, of how they interact and collaborate on research and development activities with an external partner. The SMEs discussion sought to explore business practices adopted with the University as the external source of knowledge and the routines both parties deployed to refine and recombine knowledge.

3.5.2 Selection of Research Participants

The firms studied formed a sample of a unique cohort of SMEs regularly engaged with R&D collaborations with Deakin University. They formed part of the Australian Research Council (ARC) Industrial Transformation Research Program (ITRP) to partly fund, with the Australian Government and Deakin University, the Futures Fibre Hub (FFH) at the University's Waurn Ponds Campus in Geelong. The research participants included key employees from a small cluster of SMEs that form a joint funded ARC research project with Deakin University based in Geelong. The research participants derive from five SMEs and university staff. The case study consists of four units of analysis – firm two and five are combined for the purpose of the second firm unit of analysis, as shown in table 13. The first unit of analysis consists of one firm, the second includes two firms (firms two and five) and the remaining two separate companies. In addition, several other university staff members were interviewed to support the data collection and analysis.

Table 13: Research Participants

Case Study		
Unit of Analysis	Number of Participants	Total Interviews
1. Firm One – DJs	(i) Owner/Manager (ii) University Senior Research Fellow	4
2. Firm Two – HQ [supported by local engineering KIBS firm five]	(i) Executive Research Manager (ii) University Senior Research Fellow (iii) KIBS - SME (Engineering Consultants)	4
3. Firm Three - CR	(i) Firm R&D Manager and original Co-founder (ii) University Senior Research Fellow	2
4. Firm Four - QS	(i) Inventor of original patented technology (ii) Senior Business & Marketing Manager (iii) Firm R&D Manager & Deakin Industry Research Supervisor (iv) Carbon Nexus Senior Research Fellow (v) Former CSIRO Research Professor	6
Other Research Participants		
University Research and Commercial Executive Managers	(i) IFM Executive Manager (ii) ARC FFH Research Project Manager (iii) Carbon Nexus Business Manager (iv) Deakin University Commercial Manager (v) FFH Senior Research Fellow and Manager (vi) Senior Manager Innovation Manufacturing – CRC (IFCRC)	6
Total	19	22
Total A4 Pages of Interview Transcripts	450	

The firms are diverse in terms of age, business cycle, ownership, historical background, organisational structure, key personnel and staff characteristics. They all have physical proximity to Deakin University's Waurn Ponds Campus in Geelong. Of the five SMEs involved, only two firms are not located on the university campus near to the university's research centre, with close access to both research staff and equipment. Of the two firms not located on site at the university, one is located nearby in one of the industrial estates of Geelong with its own premises and engineering equipment and staff. The other firm is based outside the Geelong Region at Port Melbourne an industrial area of Melbourne City. One firm located on site at Deakin University, has both R&D and manufacturing capacity. The two medium sized firms consist of one firm with over 150 staff (across two locations – Waurn Ponds campus and Bankstown, NSW) and the other with over 100 staff based at the university campus site. These two firms have long term historical connection with Deakin University dating back to the early 2000s. Each firm's identity is kept confidential where possible, or revealed with consent where not, but the firms consist of the following type of businesses:

Table 14: Description of Case Study Firms - SMEs

1. Firm One	A personal protective and safety clothing / apparel manufacturer;
2. Firm Two	A short-polymer fibres (SPFs) manufacturer for textiles and various textile treatments.
3. Firm Three	A composite and carbon fibre manufacturer (key innovation product item – automotive wheels);
4. Firm Four	A composite and carbon fibre manufacturer (various product items) using proprietary patent technology.
5. Firm Five	A consulting electrical and mechanical engineers - KIBS.

Table 15: Characteristics of Case Study Firms - SMEs

Firm	Size - # of staff	Age	In-house R&D capacity	Location	Technology platform / knowledge base & innovation mode	Product Market presence
1	< 20	10 years plus	No	Off site to university	Fabrics & Textile Manufacturing <i>Synthetic & symbolic knowledge base</i> • DU&I	Yes. Established and diverse markets, expanding product range / line as new technology develops.
2	< 5 – two-part time staff.	<5 years old	Yes	On site with university	Bio-chemistry /Chemical Engineering Material processing. • <i>Analytical & synthetic knowledge base</i> • ST&I and DU&I	No. Early product marketing of product innovation and technology developed.
3	> 100	10 years	Yes	On site with university	Mechanical Engineering • <i>Analytical & synthetic knowledge base</i> • ST&I and DU&I	Yes. Intermediate stage with ongoing market contracts to specific OEM customers for tailored products
4	> 150	15 years	Yes	On site with university	Applied Mechanical Engineering, Chemical Engineering • <i>Analytical & synthetic</i>	Yes. Intermediate stage with ongoing market contracts to specific OEM customers for tailored products

					<i>knowledge base</i>	
5	< 20	30 years	No	Off site to university	Applied mechanical and electrical engineering <ul style="list-style-type: none"> • <i>Synthetic knowledge</i> • DU&I innovation mode 	Yes. Established KIBS transition from supporting older manufacturing industry base to new emerging regional industries in the area.

The firms also represent a group of industries that use and apply different knowledge bases and types as part of their innovation activities and process, as identified in table 15 above. An analytical knowledge base refers to activities involving scientific knowledge that seeks to understand and explain empirical phenomena, such as ST&I – the pharmaceutical industry is an example of a scientific synthetic knowledge base. Engineering provides a typical case of applied learning DU&I in synthetic knowledge bases, whereas the creative design industries, are based on symbolic knowledge bases. The ST&I mode uses mainly analytical knowledge and scientific learning processes based on the formulation of abstract models, testing and documentation. This typifies some knowledge-creating activities in, for example, the biotechnology industry (Moodysson, 2007). The ST&I mode describes a narrower mode of innovation than the DU&I mode of innovation about the range of potential knowledge sources. The ST&I mode is thus linked to the narrow definition of innovation systems (Lundvall, 2007).

The DU&I mode of innovation is mainly based on a synthetic and symbolic knowledge base and on learning by interacting between companies in the supply chain, for example between a company and its specialised sub-contractors and/or a company and its customers. It is a more demand-driven innovation model than ST&I and is particularly useful in analysing incremental innovations in industries such as mechanical engineering. The model is particularly useful for analysing science and technology push or supply-driven innovation processes, which may result in radical innovations. Other examples include the nanotechnology industry sector, which require regular university-industry links and respective networks, more frequent than in other types of knowledge bases (Asheim, et al; 2011, p.896).

The level of confidence, investment and trust shown by these firms partnering with Deakin is confirmed via their financial contribution towards a five-year ARC research project under the Future Fibres Hub (FFH) within the Institute of Frontier Materials (IFM), Deakin University. Participating firms have previously sourced knowledge from the university to a greater or lesser extent in the past – reflecting a firm’s *prior knowledge and personal contact* that included contributing funds towards a specific R&D project under former research grants. The previous collaborations prior to the current ARC FFH project had, in all cases, involved the firm’s internal capacity – namely the senior

management such as CEO/Owner or R&D staff employed by the firm had undertaken their own internal R&D activities.

To improve the reliability of the empirical research, structured procedures for data manipulation and analysis (Yin, 2003) were applied. The following steps were considered as recommended by Miles and Huberman (1994):

- data categorisation, i.e. a breakdown followed by an aggregation of raw data carried out with the aim to unearth important characteristics and to streamline comparisons;
- data contextualisation, i.e. a systematic analysis of contextual factors not included in the theoretical framework;
- 'within-single case' analysis through explanation building procedures – this was necessary to identify the reasons underlying the relationships between the identified variables; and
- 'cross-case' analysis, carried out to compare the patterns emerged in each unit of analysis (the firms) of the case study.

3.5.3 Overview of documentary data:

The documentary data collected includes a wide range of publicly available information sourced from the internet, such as official documents like annual reports and media releases from various participants, media reports from various outlets/sources, and various government and private sector website sites.

3.6 Overview of data analysis

3.6.1 Primary Data: Open Unstructured Interviews

In preparation for the interviews a potential series of questions based of the four dimensions of Zahra and George's (2002) AC model were drafted and discussed with the project's research supervisor. This question design strategy proved to be a complicated exercise to adequately cover the multiple AC considerations and factors. A second question design method drafted a series of questions based on the few empirical qualitative multi-dimensional studies reviewed in the literature. In the end, both above methods were abandoned in favour of a less structured interview process. The interview questions were developed from a series of broad, open style questions centred on discussions to how the research participants sought to explore and exploit knowledge sources.

The open style questions principally explored how knowledge is acquired, assimilate, transformed and exploited between the two parties, with a specific focus on how the firm exploited knowledge for commercialisation (new product development – NPD) and how the university contributed to this outcome. The question design strategy sought to keep data collection as open-ended and responsive as possible, without embedding too much from previous research findings into the interview questions. In the first instance, each participant had the opportunity to describe their role within their organisation, and their general experiences working within industry and/or the university setting.

Each participant was then prompted to reflect on each dimension through a series of open-ended prompts that attempted to provide as much space for participants to use their own words and concepts as possible.

The most recent and relevant projects from each firm were referred to as examples of both the R&D (knowledge) inputs made by different participants of a NPD project, and the key outputs delivered by participants, which specifically resulted in industry scale applications of a firm's new product. The decision was made to allow for this background literature to inform open dialogue and conversation with the research participants in a constructive and friendly manner, without dictating the terms in which participants should respond. The questions had a slightly different nuance depending of the individual participant's role ('people') within their organisation and locations of research or geography ('places'), and the different perspectives they bring to the innovation process ('phenomena') from their own personal experiences.

Ultimately interview responses reflected whether the participant represented the principal source (the university) or principal recipient (the firm) of the knowledge, as such responses to the interview questions varied. The interviews took on average one hour and, in spite of the less structured style, were designed to broadly capture factors associated with the AC construct. The study provides insights to the innovation capabilities of the SMEs 'absorptive capacity', across the two phases of exploration (potential capacity) and exploitation (realised capacity) as developed by Zahra and George (2002). The narrative of the thesis covers both an intra-organisational and inter-organisational perspectives to reflect two of many AC antecedents or determinants (factors) (Van Wijk et al, in Easterby-Smith and Lyles (Eds), 2011, pp.287-288).

The research provides the participants firstly with an opportunity to discuss their insights and views from their perspective, either the industry or the university's, and secondly, provide some insights to other participants involved in industry-university collaboration transaction. These responses are derived from the participants' direct 'hands on' experience, both from an individual perspective working within a specific organisation, and collaborating with an external party, to develop and refine new knowledge in the collective research innovation project. For the researcher, this provides an informal perspective of a small selection of participants involved with research and development project between industry and a university in the pursuit of innovation. It offers an opportunity to contrast the participants' responses to identify any specific similarities, differences, patterns or themes in the overall narrative.

3.6.2 Case Study Design and Methods

The case study method is the preferred research method when examining contemporary events when the relevant behaviours cannot be manipulated. The case study relies on many of the same techniques as a history, but it adds two sources of evidence not usually available as part of the historian's repertoire – direct observations of the events being studied, and interviews of the persons

involved in the events. A case study also can deal with a variety of evidence, such as documents, artefacts, interviews, and observations. An in-depth detailed study of a few SMEs at the firm level provides practical and pragmatic observations of a firm's learning abilities [innovation capabilities] to engage with the innovation process. Specifically, as SMEs rely more on external sources of knowledge, they must be able to both access knowledge and apply it for commercial gains, particularly where it can provide a competitive edge in the market place and improve productivity. A firm's prior knowledge provides the necessary internal capacity to benefit further from sourcing additional knowledge. A business must not only know what it does well, but also where it can improve and how they can innovate to make the necessary changes to be and remain competitive in the market place.

3.7 Phase 3: Case Study Data Analysis Method

The process of analysing qualitative data involves identifying common patterns within the primary data responses and critically analysing them to address research questions - and the overall aims and objectives. Comparisons of the primary research findings to the reviewed literature are critically important for both types of studies, as well as, controversies within secondary data directly related to the research area. The following steps have been devised to reflect suggesting literature (Dudovskiy, 2015, pp.52-53) to analysis qualitative data. The data analysis is conducted using a three-fold method:

- | | |
|-----------------------------------|---|
| 1. Developing Data Analysis Codes | Adopting a 'coding structure' |
| 2. Data Analysis | Coding Analysis in the 'NVivo' V11.0 software program |
| 3. Data Interpretation: | Identify themes, patterns and relationships |

3.7.1 Developing Data Analysis Codes

Coding can be explained as categorisation of data. A 'code' can be a word or a short phrase that represents a theme or an idea. All codes need to be assigned meaningful titles. A wide range of non-quantifiable elements such as events, behaviours, activities, and meanings can be coded. There are two main approaches for coding as Inductive and Deductive coding (Krippendorf, 2004; Bernard, 2000; Marying, 2000) sometimes also known as Emergent and Priori coding (Stemler, 2001). The data analysis deploys a coding structure derived by Gebauer, Worch, and Truffer (2012). Gebauer, et al., (2012, pp.59-60) adopt an exploratory, qualitative research method; however, while their study is qualitative due to its context, it is positioned between deductive and inductive qualitative studies, being neither a test of an already developed theory, nor a development of a new theory. Rather, it is a contribution to theory-building through dialectic interaction between field studies and existing theory consistent with Strauss and Corbin (1990).

Gebauer, et al., (2012, p.61) explored their emerging theoretical understanding of the AC concept from interview transcripts, to develop chronological descriptions and emerging themes. Then they followed a fine-coding scheme in which codes were derived inductively from transcribed data. This study adopts the pre-existing coding structure developed by Gebauer, et al., (2012, p.63) as shown

in table 15 to analyse the interview transcript text in an inductive manner. The concept lends itself to this learning perspective of innovation activities that business engages as practices or routines. The adoption of this structure is used to make the AC concept operational in two ways.

1. Firstly, it allows a logical and straightforward analysis of the data to measure the relative importance of the AC concept to firm's innovation performance and how they innovate.
2. Secondly, it gives the data some 'quantifiable' aspects of the AC concept to the firms under study by the analysis of the qualitative nature of the interview transcripts from each research participant involved.

Table 16: AC Learning Processes - Coding Structure

AC Coding Structure
AC 1 Acquire
AC 1.1 Openness and recognition towards external knowledge sources
AC 1.2 Engagement in joint knowledge-creation projects
AC 1.3 Regularity of meetings with externals
AC 1.4 Motivation to use external knowledge sources
AC 1.5 Identification of new knowledge in external sources
AC 1.6 Generating information on business environment relevant to new business opportunities
AC 1.7 Acquisition of knowledge through various sources
AC 1.8 Selecting and retaining knowledge obtained from external sources
AC 1.9 Classifying and internalising acquired knowledge
AC 2 Assimilate
AC 2.1 Discussion of the acquired knowledge
AC 2.2 Achieving collective understanding of the acquired knowledge
AC 2.3 Integration of new knowledge into firm's knowledge base
AC 2.4 Dissemination of new knowledge throughout the firm
AC 2.5 Using tools for spreading knowledge throughout the firm
AC 3 Transform
AC 3.1 Creation of new knowledge based on the acquired knowledge
AC 3.2 Reconstructing acquired knowledge
AC 3.3 Facilitating transference and novel associations concerning the knowledge
AC 3.4 Discursive interpretation of knowledge
AC 3.5 Adding new knowledge to the acquired knowledge
AC 3.6 Constructive combination and re-combination of knowledge
AC 4 Exploit
AC 4.1 Applying knowledge to commercial purposes
AC 4.2 Launching innovations to the market
AC 4.3 Converting innovative ideas into commercial applications
AC 4.4 Using generated and disseminated knowledge in market activities
AC 4.5 Engaging product or service innovations
AC 4.6 Commercial use of knowledge

3.7.2 Data Analysis

The interview transcripts were coded using NVivo V11.0, by applying the adopted coding structure as discussed and shown in conceptual operational framework below. The data analysis coded relevant sections of the interview transcripts where these matched one or more of the different sub-codes for each AC stage. Therefore, parts of the same response / transcript could be coded more than once across each of the four stages. All codes are of the same value. Once the data is coded in NVivo, a simple query report was compiled for each code across each the four phases (AC 1-4) of the AC construct. The aggregated raw data was then tabulated into frequency tables presented for both single and cross cases format. This simple tabulation method shows inter-relationships across the data and provides a way to calculate or give quantifiable second order numbers such as averages, and percentages as allowed for in traditional qualitative analysis (Miles and Huberman, 1994 in Yin, 2003, pp.110-111).

The coded text query reports for each firm was generated in NVivo V11.0 and extracted to MS Excel to compile various tables to display the data. Both automatic and manual handling and manipulation of the coded data was undertaken in MS Excel to produce the tables and simple bar chart graphs and the like can be generated. Once the data is in this format a few simple quantifiable statistics are generated for each AC sub-code. The extent to which the text relates to the various codes could then be determined by a simple tally (raw count) and this is shown in various tables prepared, an example is shown in table 17. The results of the coded interview data for each of the four AC phases/stages and sub-codes can be shown in these tables in various formats, compiled for both single unit (case) of analysis and together for the cross-unit firm analysis.

Table 17: Example Interview Coding Analysis – AC 1 Acquire Firm 1

AC 1 Sub-codes	Code Text References
AC 1.1 Openness and recognition towards external knowledge sources	14
AC 1.2 Engagement in joint knowledge-creation projects	17
AC 1.3 Regularity of meetings with externals	4
AC 1.4 Motivation to use external knowledge sources	12
AC 1.5 Identification of new knowledge in external sources	8
AC 1.6 Generating information on business environment relevant to new business opportunities	3
AC 1.7 Acquisition of knowledge through various sources	6
AC 1.8 Selecting and retaining knowledge obtained from external sources	6
AC 1.9 Classifying and internalising acquired knowledge	0
AC 1 Total	70

This method allows for the data to be examined within the single unit firm and across the units and for identification of patterns within and between the firms. A firm's AC is more immediately evident when the interview transcripts are explored thoroughly. Many of the AC learning processes do exist, but it takes a deeper interrogation with the interview analysis and the relevant literature, to draw some possible examples, as discussed further below and in the case study itself. In the last chapter of the thesis, the analysis brings together the cases in relation to the literature reviewed and the

theoretic framework adopted to explore how SMEs innovate. The cases show how each firm developed their AC, along with associated benefits, as they sought knowledge in collaboration with a university. Using the NVivo coded data analysis processes as evidence it becomes clearer the extent to which a firm's narrative can be viewed through the AC lens. When the data is in this format it can be analysed in more detail by adopting a 'content' text analyses of the interview transcripts. This is achieved by drawing upon the relevant matching coded interview transcript text, which then involves proceeding to the last step. A typical exemplary coded transcript interview text is highlighted below.

Name: AC 1.2 Engagement in joint knowledge-creation projects

R 4.1

So, for example, we did the Ford air intake duct, that wasn't using the QS technology but what it did do was qualify us with a global OEM, qualified our material, qualified our capability which then leads to other projects.

What do you mean when you qualify it, is that the class one auto?

You're qualified as a supplier. So, *the material that we used for that Ford duct, the part has been qualified and approved by Ford*, so straight away when a new project comes up you're in their database as a qualified provider of composites. Now, if you're not in that database you've got to go and do cold calls, it's a lot harder to win business.

A simple interpretation of the above interview transcript indicates that the firm's pursuit of qualifying its technology involves forging stronger relationships, respect and trust with its partnering OEM customer (Ford USA) to secure a successful product development outcome. In this example the innovation performance is the product outcome that created a light weight composite fibre air intake duct used as a componentry part for new vehicles manufactured by Ford US for the American domestic market.

3.7.3 Data Interpretation - Identify themes, patterns and relationships

As discussed in chapter two, the qualitative data analysis provides insights to the innovation capabilities of the SMEs as developed by Zahra and George's (2002). Unlike quantitative methods, in qualitative data analysis there are no universally applicable techniques that can be applied to generate specific findings. Analytical and critical thinking skills of researcher plays significant role in data analysis in qualitative studies. Therefore, no qualitative study can be repeated to generate precisely the same results. Nevertheless, there is a set of techniques that you can use to identify common themes, patterns and relationships within responses of sample group members in relation to codes that have been specified in the previous stage. The coded responses when analysed presents several commonalities and differences when the results are compared within and across the units of analysis.

The data analysis is firstly organised to correspond to the two broad stages of four AC phases. Within each phase of the AC phases the dimensions attributed to them from the adopted coding structure is shown. Essentially the focus for much of the data analysis is with the most frequent sub-codes within each AC stage, which for this case study data analysis represents one of the following:

- those sub-codes achieving a response that is either on average or higher than the total average for that single individual firm case; and
- the analysis across the cases, those scores on average or above the total average for all firm cases.

Table 18: Example of Total results for Individual and All Firms – AC 1 Acquire

AC 1 Sub-code	Firm 1	Firm 2	Firm 3	Firm 4	Total Firms	Total Avge	%
AC 1.2 Engagement in joint knowledge-creation projects	17	35	14	23	89	22.35	25.2
AC 1.1 Openness and recognition towards external knowledge sources	14	27	11	18	70	17.5	19.8
AC 1.4 Motivation to use external knowledge sources	12	21	4	18	55	13.8	15.5
AC 1.5 Identification of new knowledge in external sources	8	21	5	11	45	11.3	12.7
AC 1.3 Regularity of meetings with externals	4	12	1	5	22	5.5	6.2
AC 1.6 Generating information on business environment relevant to new business opportunities	3	10	1	8	22	5.5	6.2
AC 1.7 Acquisition of knowledge through various sources	6	5	6	5	22	5.5	6.2
AC 1.8 Selecting and retaining knowledge obtained from external sources	6	6	1	8	21	5.25	5.9
AC 1.9 Classifying and internalising acquired knowledge	0	1	1	6	8	2	2.3
Total	70	138	44	102	354	88.5	100
Single unit firm Averages	7.78	15.3	4.89	11.3	39.33		11.10 percent

The single firm frequency results – an example presented above table shows the extent of the strength of each ‘sub-code’ for each firm. Within the single unit cases, as the data reads down the column, it reveals AC 1.2 *Engagement in joint knowledge-creation projects* as a strong pattern, which is consistently the highest sub-code across all the firms. By examining the matching coded interview transcripts greater observations come to light that provide details to the patterns identified in this section. For the most part this is presented in the case study and last chapter, when attention is given to the relevance of the literature relied upon. This form of data analysis can then support several conclusions that will be discussed in the chapters to come.

Table 19: Example of Frequency Results for Individual and All Firms

Frequency of AC 1 Acquire – ALL Firms	Firm 1	Firm 2	Firm 3	Firm 4	All Firms
AC 1 Sub-code					
AC 1.2 Engagement in joint knowledge-creation projects	1st	1st	1st	1st	1st
AC 1.1 Openness and recognition towards external knowledge sources	2nd	2nd	2nd	2nd	2nd
AC 1.4 Motivation to use external knowledge sources	3rd	3rd	5th	2nd	3rd
AC 1.5 Identification of new knowledge in external sources	4th	3rd	4th	4th	4th
AC 1.3 Regularity of meetings with externals	7th	7th	7th	9th	5th (equal)
AC 1.6 Generating information on business environment relevant to new business opportunities	8th	8th	8th	5th	5th (equal)
AC 1.7 Acquisition of knowledge through various sources	5th	5th	3rd	8th	5th (equal)
AC 1.8 Selecting and retaining knowledge obtained from external sources	5th	6th	6th	5th	8th
AC 1.9 Classifying and internalising acquired knowledge	9th	9th	9th	7th	9th

All the interview data was used for the data analysis. The top three most frequently coded dimensions within each AC phase were identified, and this process has informed the content analysis of the interview transcripts, to enable inductive observations about patterns within and between firms. This involved examining the specific responses by the research participants to assist with making meaning, particularly in context of any relevant reviewed literature. This analysis is further organised through the conceptual theoretical framework introduced in the literature review chapters above.

4 CHAPTER FOUR: CASE STUDY

This chapter explores the AC concept through the experiences of five SMEs that have collaborated with Deakin University. The data collected consists of both primary and secondary sources of data, primarily interviews and public information. The interviews focused upon the participants' explanations to how they engaged with the University on research and development activities and other relevant partners. This case study analyses the interview responses based on the correspondences between interview responses and the AC construct developed into a coding framework to organise the data. The data analysis was conducted with NVivo V11.0 that allowed for patterns and themes to emerge related to the adopted AC coding structure from the literature. The data analysis method is primarily qualitative, but some quantitative observations were also possible, including frequency of responses, with average and percentage scores. The case study draws attention to the exploration and exploitation of new knowledge and technological advancements by each firm, in order to illustrate the relationship of AC to a firm's product innovation performance as an outcome of the collaborations. Chapter five will then build on the analysis presented here, to reflect more explicitly on the overall research questions and reflect on possibilities for further research.

4.1 Firm 1

4.1.1 Potential Absorptive Capacity

Acquisition (AC 1) Late 1997 – mid 2000s

Firm 1 was able to draw on prior knowledge, which was developed from established experience and well-developed networks in the textile and clothing manufacturing industry. Prior to establishing the firm in 1998, the owner operated a denim jeans manufacturing plant from 1986. The firm's interest in the use of science and technology resulted from a chance conversation while attending a trade show in the US. This introduced the firm to the novel idea of deploying an abrasive resistant textile fabric to manufacture protective motorcyclist clothing. The clothing provides protection to specific parts of the body that are vulnerable in a motorcyclist accident when a rider falls and slides along the ground at speed. The firm's owner then devoted full attention to developing a prototype protective garment. First released in 1997 for motorcyclists, it contained a mixture of Kevlar® and denim, and later Dyneema®.

Initially a few product prototypes were 'road tested' in an infamous marketing campaign that involved the owner being dragged along a road at various speeds whilst wearing the protective garment. The initial interest in the product convinced the owner to sell the firm's jean manufacturing operations in 1998 to focus on this new venture. The firm first canvassed the product to a few potential local Australian stakeholders, both government agencies and industry, without success. Despite this setback, the firm persisted with the product development concept by directly consulting with various motorcyclist clubs on the earlier prototype. The innovative product was launched directly to motorcyclists at the Australian Motorcycle Grand Prix and later at international trade expositions, which created sufficient interest as motor cyclists heard through word of mouth of the product's

quality due to direct product marketing to the motorcyclist fraternity. The product feedback gave the company the confidence to proceed with increasing the scale of manufacturing.

Early in the firm's evolution it acknowledged the need to engage with scientific knowledge and testing as part of its NPD and innovation strategy. Unfamiliar with the technology, but with an open mind, the firm sought to learn more about the science and technology behind protective clothing manufacturing. This learning is motivated by a strong sense of social responsibility to the consumer, along with a need to acquire better intelligence around the product development and develop brand integrity in the market. Ultimately, the road safety aspirations of this unique product led to a search for expertise in fabric, knitting and textile technology. The firm's acquisition of knowledge through joint knowledge creation projects evolved from both dyadic and multiple relationships namely with the international testing facilities, suppliers such as knitters and knit technology and other agents in the firm's VC.

Assimilation (AC 2) Mid 2000s

Assimilating new knowledge was achieved through a 'trial and error' learning process by the firm in its early prototype NPD design activities. The firm deliberately explored new knowledge about textile science and technology of fibres, textile design and abrasive resistance properties for its business operations and practices. The firm has sought the use of scientific testing and R&D to expand its product quality and range since 2005 when it began to work with Dr Roderick Wood from Cambridge University. The nature of the fibres the firm works with requires specific technical capabilities and uniquely designed knitting machinery and specialist technical industry expertise. This machinery was not readily available in Australia but, by chance, the firm acquired the necessary equipment and qualified operators in the USA to progress with the testing (trial and error) of different knits to further develop the product.

The assimilate phase sees the firm emerging from initial searches for technological change to its existing knowledge bases and advance its business learning to procure new or extend its existing scientific or technological platforms. Developing new knowledge through a 'trial and error' learning processes is manifested in the firm's early prototype, NPD, design activities. For these activities, the firm worked with Dr Wood, who developed the fabric abrasive testing machine known as the 'Cambridge Machine', which tested for abrasive and seam-bursting resistance properties of fabrics used for protective clothing for motor cyclists. The machine simulates the impact a rider sustains upon contact with ground surface (such as a bitumen road) and measures the duration of garments protection in seconds. The longer the fabric remains intact before disintegrating, greater the level of protection in theory and applied practice. The initial testing of the firm's products with Dr Wood, ultimately led to a recognition of the need for faster and more detailed testing results that provided better analytics of why specific textile knits performed better than others – and thus to a search for additional technological scientific testing capability. The firm spent a larger time assimilating the new knowledge of applying the advanced fibres into protective clothing, working with its suppliers as well as the international testing facilities.

The firm spent several years sourcing new knowledge from different testing laboratories in the UK. The development of the CE Level 1 products in 2010 was a result of working with a private research and testing facility called SATRA.³ SATRA was introduced to the firm by Mr Paul Varnsberry, an industrial consultant in the UK, to extend the firm's knowledge base. The company was the first to achieve a CE Level 1 approval in 2010 its riding protection clothing, and prides its business on ensuring customer protection, scientific authenticity, brand loyalty and high level of social consciousness. The firm's product innovation typically followed the three-phases of the NDP process. When the firm's owner founded the company, the desire was to create the safest motorcycle clothing possible. The first step of this journey meant sourcing what standards existed and learning to use them as a 'yardstick' by which to measure the effectiveness of company's designs.

This ultimately led the firm to the CE EN13595 tests and CE approval. Several years after the initial disinterest in the firm's product development, the novel product became well regarded in the global market place and commercially successful. The firm was the recipient of the prestigious Red Dot international industry design award in 2011, recognised in the Australian Innovation Systems Report (2012, p.63). This was followed by another product that achieved the highest level of personal clothing protection standard of CE Level 2 in 2013. The AC of this small globally networked Australian firm repeated its early success by receiving the Red Dot Award again in 2014. Ultimately the pursuit of external knowledge is ongoing, with the firm forging its collaborative partnership with the University from 2013.

The firm set the European industry standards as the benchmark for its product innovation across all its markets and product range. The firm achieved the European clothing protection standard or 'CE Level 1' in 2010. It went on to achieve protection levels at and beyond the 'CE Level 2' in 2013.

At the end of this period, the firm was introduced to Deakin University through a Federal Government initiative to support industry connections to researchers. These prior experiences and product success equipped the firm with an internal capacity to engage in further innovation activity, motivating the firm to engage with the University in 2013. Since then, the firm and the University have refined the firm's technology capability further, with incremental improvements to its existing product range. It released a cyclist protective product range in 2015-16 and most recently new improvements to its patented protective lining material that trades under the name of RooMoto™ used in rebranded product released at end of 2017 and 2018. These products contributed to continual refinement of comfort, weight and protective aspects to the technology of the fabric knits used in the product range.

³ <https://www.satraprotection.com>.

4.1.2 Realised Absorptive Capacity

Transformation - Post 2011

The firm's realised exploitation to commercial success of scientific and technological knowledge has been validated by both international and location industry awards. Ultimately, it is the pursuit of incremental advances to its products which led to the firm establishing a relationship with the senior university management and research staff at the IFM at Deakin in 2013. It continually refines its products and introduced a product range for road cyclists in 2015 as an outcome of a joint research project with the University, supported by Federal Government funding in 2013 and 2014. The experience of collaborating with the University on joint knowledge creation for the firm has been positive. This is an outcome of participating in joint funded R&D work under the previous Federal Government's Enterprise Connect program.

The Federal Government program supported the placement of researchers from universities or public research agencies into businesses where such a placement would help to develop and implement a new idea with commercial potential '*to develop and review new materials and concepts for fabrics and garments*'. Two research projects were completed under this program. Both research projects related to layered materials with various combinations of heat-retaining, heat reflecting, moisture-wicking, or waterproof properties. This textile technology and testing regime was conducted with the University working with the firm and its international textile knitting manufacturers. As result they have been able to refine the fibre applied in the products to reduce the weight of the garments by up to 30 percent whilst increasing the abrasive resistance performance. The products have also become light weight, breathable and comfortable to wear with adopting the wicking knowledge.

A cooperative arrangement formed to develop an additional product line to the firm's market, focused on professional and recreational road cyclist apparel/clothing market. Since that first meeting with Deakin University in 2013, the firm has been working with the University to get its products refined and tested for greater abrasive protection, along with consideration of other factors such as comfort, fashion sense of the garments, and fabric breathability (cooling or warming properties) to improve a rider's experience. This process is based on textile research and testing and knitting technology of the textile manufactures and associated machinery. As the owner has described: "*The outer layer, the denim, is pretty easy, but to get the protective lining right and to where we are now has been some years, but we have made a lot of progress in the last six months. A lot of progress once we understood exactly what it was we had to do, and we could get the manufacturers to invest in the equipment to do it and put the time and effort into getting the right fibres from DuPont and the right fibres from DSM, because they're very fine fibres now.*"

Working with the abrasive resistant fibres is very harsh on knitting equipment as the owner discusses: "*I think in a normal pair of jeans the needles might last 300 pairs whereas ours they last ten. So you're changing needles, you've got to have very special needles to sew with and all that sort of stuff, special things to cut because it's very difficult to cut as well.*" "*Equipment is specifically designed to*

deal with it and the people have to be trained how to use it as well. You're dealing with a number of different fabrics that have like the lining, we have to lay it out overnight and it's susceptible to different climatic conditions and what have you. So, it's all pretty tricky to work with to get it so it all fits right and looks right, so we've had a long time." The firm shows an example of an innovative small business with a capacity to investigate external knowledge when presented with a novel idea, in order to produce an innovative product and to overcome technological and marketing problems along the way.

The open-mindedness of the firm's management drives the pursuit of knowledge to learn more about science and technology associated with fibres and textiles providing personal protection qualities such as abrasion resistance in road motor cyclists clothing. The initial product development range explored for a new market targeting recreational and professional cyclists was pursued by the firm with the introduction of new exploratory textile technology developed by the University. The firm and university researchers both recall the time when the two parties came together to explore creation of application of new knowledge into the firm's NPD process. The relationship developed with the University has forged both a formal research program under the ARC hub, but also everyday interactions and tacit exchanges through a Deakin University staff member embedded in the firm's operation. The role facilitates a two-way exchange of knowledge, where the staff member is getting industry exposure to the firm's local and international operations from site visits to the firms preferred knitters of the textiles used in its current CE level 1 range from China operations to its CE level 2 production in the US and Europe. The manufactured clothing comes from China, Fiji and Australia.

Exploitation - Post 2013

During this period the business has confronted several issues. With the push for increased protection levels and seeking the relevant CE levels, the firm has accurately exceeded the level 2 CE standards. It is also in the final stages of releasing a new product that could not be discussed in any detail. In the pursuit of excellence and quality of product innovations, the firm has had to contend with less reputable companies producing inferior quality products to the market, falsely advertised as made with Kevlar. The firm reflects the typical struggle smaller firms face between exploring new knowledge developments and exploiting its current product innovations. This means the firm's employees are deployed to carry out daily routine business practices. At the time of the study, the core business is largely devoted to ensuring its product range is tested and labelled to meet the new European motorcyclist clothing safety requirements. The new European clothing safety standards are lower than the former ones; however, all products are mandated to demonstrate they meet the new standards. The firm's products also need to be rebadged with the approved new standard level label. This is at a cost to the firm, which has already exceeded the previous higher standards without being required to.

The firm takes a long-term view on innovation and technological change as continually evolving, with growing opportunities for different fibre development. The integration and use of the fibre required the firm to develop suitable knitting machinery/technology and abrasive resistance testing to refine

the knitting structure to achieve the CE European standards. The knitting structure is adopted by the firm's contracted knitters – knitting manufacturers. The production of the garments at the firm's various overseas manufacturers produces a different range of products at the CE 1 and 2 levels. There is concern over the potential to leak to would be imitators, which could undermine the 'first mover' strategy that, in a relatively small market, has allowed the company to excel in its specific niche, earning recognition from international industry design awards. The firm restricts its knitting technology to specific manufacturers based on selective revelation [disclosure] of its 'know-how' - for example, the firm does not manufacturer its highest protective garment range from its Chinese manufacturer due to issues of confidentiality and trust.

Furthermore, by working with its suppliers across its supply chain, it has secured a strong partnership as a reputable manufacturer that nurtures the use of technological advanced fibres supplied by the DuPont Company. This dedication to high standards and innovation positioned the company as a preferred licensee to use the DuPont's fibre range. The company has secured this alliance relationship with this supplier; and DuPont has indicated it wishes to work with the firm and the University to apply new fibre and textile technology developments in the future. The firm is currently developing a new product range that builds upon its exploratory work with the University. The firm's ability to engage in such projects is restricted by its size and time constraints. Staff members from the firm are engaged in design work for release of new apparel that uses its current product technology range, while the owner takes primary responsibility for working with the University on product exploration. The collaborations SMEs negotiate with the University thus vary with the phases of NPD process, and ultimately the successful outcome of collaborations informs the innovation performance and outcomes of each firm. Today the science has been developed to now demonstrate over seven seconds of protection that can minimise soft skin-tissue damaged by up to 300 percent. Specific details of this new product are not available, but it is understood the product range will be potentially manufactured locally in Victoria.



Figure 8: IFM Open Day November 2017 – Display of Firm's Product Innovations

Table 20: Timeline of Firm 1 (DJs) Product Innovation Development

AC 1	AC 2 & AC 3	AC 4
<p>1997 - mid 2000s</p> <p>Exploratory use of Kelvar® protecting lining in early prototypes using textile research into the use of supplied advanced fibre technology with UK university in late 1990s and private testing laboratory in mid to late 2000s.</p> <p>2013 onwards</p> <p>Firm sought University assistance to develop product prototypes for a new market based on technology used in existing product ranges. Firm sought University assistance to develop a product for a new market based on technology used in existing product ranges.</p>	<p>2005 onwards</p> <p>Early development of textile research into the use of supplied advanced fibre technology that lead to early university testing in the UK prior to CE Level certification in 2010.</p> <p>2010 - achieves CE Level 1 protection standard</p> <p>2011 Onwards</p> <p>Developed its own knitting technology with suppliers. Initial testing with UK university developed new knowledge on different knits and weaving patterns to confirm with early clothing protection standards developed in the UK. Later developments with finer and more detail testing with equipment at private laboratory developed the first CE Level 1 product range.</p>	<p>After 2010 achieving the CE Level 1 clothing protective product further testing 'n' trial work between the firm and its knitting partners and supplied fibres from DuPont and Diamer developed the firm's RooMoto™ protective lining textile incorporated from.</p> <p>2013 - achieves CE Level 2 protection standard</p> <p>Post 2017 - ongoing</p> <p>Further weight reduction achieved – move towards single lining protective garments. Release of new products with weight reduction and increase soft tissue protection.</p>
<p>NPD 2015-2016 ongoing</p> <p>Firm sought University assistance to develop a product for a new market based on technology used in existing product ranges. In 2015 developed new product range for road cyclists that have not been a focus for the company, with little time spent to market the product developed with the University.</p>	<p>University able to contribute new knowledge to existing product designs by investment in its research program with acquiring both equipment and new research staff in the form of a textile design engineer and personal safety injury prevention researcher linked to NSW Road Safety and Motorcycle Council of NSW (MCC).</p> <p>http://www.abc.net.au/catalyst/stories/4433001.htm</p>	

4.2 Firm 2

4.2.1 Potential Absorptive Capacity

Acquisition

The second firm collaborates with Deakin University to transform applied research developed by the University and a 'spin-out' Bio-tech company (Cytomatrix Pty Ltd) for commercial industry applications. The success of the company is built upon several years of University research, and more recently in association with its industry partners Cytomatrix Pty Ltd. The technological achievements of the University's Senior Researcher are the result of the research into a groundbreaking technique to produce Short Polymer Fibres (SPFs) that began as an ARC Linkage Project in 2008-09. In 2013 the IFM funded a project (\$245 000.00) that allowed for ongoing research of SPFs to collaborate with its industry partners that included Cytomatrix and Austeng Pty Ltd a mechanical engineering firm in Geelong. Austeng is a third-generation family owned SME that built a larger prototype machine to provide a 'prove of concept' technology platform.

The lead Senior Researcher stated that working with industry gave the University the opportunity to advance the technology whilst supporting local regional industry growth potential and skilling of future labour force. The two parties have developed a world-first manufacturing process for a new class of high-value materials to promote the growth of stem cells. These new materials open a wide range of applications in bio-technology, medicine, materials science and other fields. The collaboration represents a successful, dynamic and interactive relationship between academic and industrial partners, which has realised a multi-scale approach to short polymer fibre and textile manufacturing. Cytomatrix acted as a '*translation company*' whose core focus was to develop and commercialise technologies developed by academics.⁴

Cytomatrix's CEO commented that:

"Austeng was chosen as its industry partner due to its proven track record in the area of developing and commercialising technologies and due to its ability to cover all engineering aspects of the project from design, manufacture through to installation/commissioning and ongoing modifications and servicing."

The design process consisted of a fruitful and ultimately successful sharing and interchange of ideas and concepts from experts with quite different disciplines in academia and industry. A key goal of the pilot plant was to demonstrate in-line deposition of short fibres onto filter membranes in a rapid and reliable way. In a concerted effort, the various project partners contributed unique '*know-how [implicit and non-codifiable skills]* and know-do' with Austeng providing fluid-systems engineering expertise, and Cytomatrix/Deakin providing the short fibre 'know-what' and rapid prototyping capabilities including 3D printing. As the owner of Austeng discusses, the evolution of the firm's services working

⁴ <http://www.austeng.net.au/project/prototype-nanofibre-machine-for-the-creation-of-stem-cells/>

with industry and the University has been a core business strategy post decline of the traditional large-scale manufacturing sector in the Geelong Region highlighted in an article published recently.⁵

The Senior Researcher from IFM adopted an applied industrial approach to research by working with business and industry partners and was the recipient of three IFM awards in 2015 for research, intra-University collaboration and entrepreneurship. The researcher was invited to the firm's parent Swiss Headquarters for the inaugural company Innovation Summit in July 2016 and was featured on the ABC TV News speaking about being a researcher and working with industry to generate new jobs, in a special feature focusing on Geelong (IFM Annual Report, 2016, p.14). This collaboration between Deakin, and existing industry partners was extended to develop short fibre production capabilities for the Filtration Industry to produce a second larger version of the machine in 2014. The Managing Director of Austeng commented that *"it was great to see academia and industry collaborating to produce such a good outcome for both parties and the Geelong region and to be recognised by engineering peers for the underlying engineering innovation and development."*⁶

The IFM's strategic business plan adopted its multi-disciplinary scientific and technological capabilities to allow responsive collaborations to research funding opportunities and specifically with relevant industries. This is driven to ensure knowledge is created and exchanged to enhance its impact to potential commercialisation applications by existing businesses and support new industrial development scenarios for the region. The 2014 project was supported by a grant of \$500 000.00 from the Victorian State Government as part of the 'Skilling the Bay' program⁷ to allow for technology transfer of Deakin University's IP to Cytomatrix. The Skilling the Bay was initiated by The Gordon TAFE in partnership with the Victorian Government, Deakin University and the City of Greater Geelong (IFM Annual Report, 2013, p.16) as part of the Geelong Future Industry Project. The larger second prototype machine completed in 2014 created a potential new manufacturing capability and employment opportunity in the region, building on Geelong's long history of innovation in the textile and fibres industry.

Assimilate

This firm's level of AC and innovation success is derived from prior research undertaken by the University since 2009 after Deakin IFM Bio-Materials scientists developed a small laboratory prototype synthesis machine for processing SPFs. In 2013 this technology was advanced further by a university spin-out bio-tech company, formed by a University staff member and a local engineering firm to produce a more advanced industrial prototype machine. The following year this same group was able to scale up the machine to a larger industrial size to process greater volumes of fibres. The founding member of the Australian subsidiary relocated to the Greater Geelong region after living

⁵ <http://aicd.companydirectors.com.au/membership/company-director-magazine/2017-back-editions/october/rebooting-the-business>

⁶ <http://www.austeng.net.au/about-us/awards/>

⁷ <http://www.thegordon.edu.au/stb/skilling-the-bay>

abroad working and inadvertently forged a collaborating research program with the University sometime later. The SPF processing technology was an accidental (serendipitous) and fortuitous discovery by the firm's chief research Executive Manager at a University Open Day, as he described: *"I went to a presentation at an innovation day that Deakin University held, actually the Institute for Frontier Materials...there was one talk where they were spending some time talking about fibres and there was one slide that was put up on the screen very briefly and I looked at it and it was just literally 30 seconds on the screen and what's that about? I recognised the material and I'd been trying to think of ways to produce materials like that and I could tell from the slide that the process was very interesting in terms of ability to scale it up. Then the slide went away, and I realised that that's quite interesting and I went across and talked to the researcher straight after and said, "We should talk some more".*

Whilst listening to this presentation, a chance discovery took place to explore a possible solution to an industry R&D problem that had intrigued the firm: *"One of the things we were always looking for were different types of ingredients that we could include in textile treatments and one particular category of ingredient was based on polymer structures, but I hadn't identified a good way to make those types of ingredients in larger quantities".* This revealed a potential application of Deakin's technology to the firm's own research and technology gap. A conversation with the IFM research staff afterwards created the beginnings of collaboration between the firm and the University. Further discussions with the University about the SPF project was initiated by the firm that convinced the firm to establish a collaborative working arrangement culminating with ongoing joint research that exists today. The firm, an international company, developed its Australian subsidiary company in April 2014 and operates from the Deakin campus working alongside the IFM's researchers.

4.2.2 Realised Absorptive Capacity

Transformation

Since the formalised research arrangements were made between the firm and the University in 2015, the firm has collaborated with the co-creators of the SPF synthesising machine (Cytomatrix Pty Ltd and Austeng). After the initial, small, laboratory-scale machine was designed by the University in 2009, it has been scaled up further with two additional larger machines in 2013 and 2014. In November 2014 the firm entered a Joint Venture Agreement with Cytomatrix Pty Ltd to develop the SPF technology into industrial scale capabilities to manufacture short polymer fibres and a \$2 million joint research program with Deakin to develop the University's original technology. The transformation of the new knowledge into the firm's knowledge based was assisted by a 'Next Generation Manufacturing' grant (\$1.3 million), to establish an industrial scale manufacturing facility in Geelong for SPF materials for the global performance additives market. As discussed by the firm's Executive Australian Manager, the venture is aimed to build a manufacturing capability for the industrial production of high-value SPF materials for the domestic and export markets.

In 2015 IMF carried out research in the Bio-Materials group focused on two broad aspects: biological characterisation and development of a stem cell expansion system; and establishing novel methods

for large-scale production of SPFs for a diverse range of applications ranging from filtration to sensors. A five-year major collaborative research program with partner HQ Pty Ltd began in January 2015. This program is based on the transfer of IP and partial commercialisation rights to HQ and Cytomatrix. The program focuses on both production and application aspects for short ultrafine fibres. This work is now generating new commercial opportunities for short ultrafine fibres and is expected to continue to grow the SPFs technological platform. *“HQ Australia will scale up and industrialise the process developed by Cytomatrix and the IFM/School of Engineering team and will actively position novel short fibre materials in the global market for high-performance additive materials,”* HQ Executive Manager said.

Exploitation

The exploitation of the new knowledge into the firm’s knowledge based was assisted by \$1.259M funding grant from Federal Government under the Next Generation Manufacturing funding program. In 2016 the firm achieved technological advancement with a new SPF machine capable of producing sufficient volume of fibres to supply its Swiss manufacturing plant to produce its new product range called ‘Real Silk’: *“that’s just one product and a pipeline product, so that’s just the starting product”*, the firm’s Executive Manager said, elaborating:

“So you were involved in helping design the up-scaled synthesis pilot machine?”

Correct. All of that scale-up work was done directly between HQ Australian and Deakin.

Can you elaborate on some of the processes that happened between the two parties in that context?

The nature of this technology is that this particular approach hasn’t been done anywhere else in the world, so we’ve got to find our way through it off the back of research, so essentially knowledge-generation and understanding-generation.

So that in its initial sense was defining the scale-up focus as a research project interaction and identifying what are the key areas that are unknown that need to be addressed and then identifying strategies to generate the information we needed.”

As part of the broader Geelong Carbon Cluster, a joint initiative between Deakin University and allied government partners have recently opened ‘ManuFutures’. This is a commercially-based, purpose-built advanced manufacturing innovation hub located within the heart of the University’s Geelong Innovation Precinct. The facility is a major investment partnership between the Victorian Government and Deakin University.⁸ Leading the way as an industrial accelerator for future technology enablement, ‘ManuFutures’ will support up to 15 enterprises and 150 people involved in sustainable manufacturing industries from post incubation (proof of concept) through to multi-nationals. It will provide flexible space and a stimulating and supportive environment to generate advanced products and manufacturing technologies.

⁸ <http://www.deakin.edu.au/sebe/manufutures>

During 2017 the firm conducted several marketing events of the new textile fibre product to European and Asian manufacturers to guarantee customers purchasing contracts. One customer of the firm includes bedding manufacturer 'Bekaert Deslee' who will create a comfortable, luxurious and indulgent sleeping environment and launched their mattress products adopting the use "HQ Real Silk" fibres in 2016.⁹ In May 2018 the firm released its second product innovation success to extend the collaborative working relationship with the University's ARC Research Hub for Future Fibres. The new product involves the SPF technology to develop a range of "no fuzz" treatments that reduce unsightly pilling and make garments look and feel newer for longer. "The key to avoiding pilling is to either remove fluffy fibres or to stabilise the fabric structure so fibres can't easily loosen and tangle," said IFM Senior Research Fellow Dr Alessandra Sutti.¹⁰



Figure 9: Commercial scale Synthetic Fibres on display at IFM Open Day November 2017

⁹ http://www.yarnsandfibers.com/news/textile-news/HQ-brings-new-textile-finishing-technology-HQ-real-silk-market#.WvZqw_7ouUk

¹⁰ <http://invenio.deakin.edu.au/reducing-the-fuzz/>

Table 21: Timeline of Firm 1 (HQ) Product Innovation Development

AC 1	AC 2 & AC 3	AC 4
<p>2009-2011</p> <p>After several years of applied R&D Deakin with spin-off firm Cytomatrix (former Deakin University academic researcher) University and an allied firm developed.</p> <p>2014-2015</p> <p>Firm acquired licensing to University technological and enters into equity agreement with third party to build first large-scale proof of concept prototype fibre synthesising machine for potential industrial scale processing of fibres over this period</p>	<p>AC 2 2011-2013</p> <p>University and an allied ‘spin-off’ firm developed an applied technology to process short polymer fibres with an initial synthesising machine developed over this period.</p> <p>AC 3 2015-2016</p> <p>Industrialisation scale of technology to produce liquid fibre for synthesising into a useable fabric for applications for surface textile treatments as a protective layer for variety of uses, specifically for comfort, and breathability factors (<i>cooling – maintaining body temperature – assists with perspiration, etc</i>) and wet weather proof.</p>	<p>2016</p> <p>First product innovation released in mid-2016 followed by second product in early 2018 that reduces pillaging of fibres to reduce textile wear and tear and improve aesthetic and design properties to fabrics.</p> <p>2016-2018 ongoing</p> <p>Deakin with said case study firm combines knowledge to enable the applied R&D to be scaled up to a larger machine to produce industry capacity to launch its first commercial product innovation from this technology platform in 2016 and again in 2018.</p> <p>2016-2018 ongoing</p> <p>First product innovation releases mid 2016 followed by second product in mid-2018.</p>

4.3 Firm 3

4.3.1 Potential Absorptive Capacity

Acquisition - Post 2004

This firm is the younger of the two largest in this study; it was established in 2007 with origins in advanced materials research and development and vehicle engineering. A student led team from Deakin University invented a one-piece carbon fibre composite wheel in 2004 and continued to develop the technology over the following three years. The firm emerged from this student project (Formula SAE program) to consist of a team of four people conducting exploratory applied technical engineering R&D from a suburban Geelong car garage in 2007. Today it is a global exporting business that employs over 150 people some ten years later:

“It started a bit earlier than that,” engineering and design director Ashley Denmead says of the company’s official establishment. “It started while we were at university doing undergraduate work in mechanical engineering and working on a Formula SAE program. We were designing and building a race car from scratch. We thought it was a pretty good idea to make the wheels out of carbon fibre. It was easy to recognise, even at that time, that the wheels were the most important area to save weight. ... **This was 2004 to 2007.**”

Denmead's side project blossomed into an obsession worth more than class credit. As Gass, Dingle, and commercial director Nick Batchelor secured private, personal, and governmental grants, Denmead and his band of talented young engineers went into high gear in their garages and labs. The fledgling company operated inside a former university warehouse in Belmont a suburb of Geelong before moving to its new headquarters at the Waurn Ponds campus site.

As one of the company's start-up owners explains, the firm includes former senior engineers from Original Equipment Manufacturers (OEMs) companies involved in chassis development and drivetrains, as well as senior manufacturing executives from automotive component suppliers, R&D specialists from the aircraft industry, industrial composites manufacturing specialists and numerous PhDs with materials and structures knowledge.

In 2007, a group of them decided to try to commercialise their work, and, with a small Federal Government grant, the company was formally established. The current CEO Mr Jack Dingle came on-board a few months later. Whilst the firm's CR-9 wheel was first made available for sale to the public in 2008, it was not to 2010 that traction with international OEM approval and subsequent sales in the aftermarket area with top luxury European car manufacturers from 2012 onwards. The company's wheels are now also to be found on OEM vehicles. *"From around the beginning of 2010 things got going in earnest,"* Dingle recounts. *"That's when we had prototypes built and tested on vehicles and got into Europe and the major OEMs there with these prototypes, and North America soon afterwards. Over the following four years we dealt progressively with the questions, the scepticism, the interest and the direction provided by talking to customers, then working away back in Australia to solve the issues and develop a variant of the technology that met their requirements and was as manufacturable as possible."*¹¹

From the outset the firm adopted a clear strategy of understanding, meeting, and ultimately exceeding the OEM standards prior to any product being launched into the automotive market.¹² The firm spent several years initially testing the product through the best testing facilities and equipment available. This took the firm to Germany, where it sought initial clearances to meet high level stringent mechanical engineering design standards for high performance sports cars. The challenge for industry in working with a potentially disruptive technology goes beyond the science of carbon fibre. The benefits of the technology are obvious; applying it in a cost-effective way is another, Dingle says. This approach has ensured that the most rigorous standards required by European OEMs: *"We've had multiple OEMs conduct quality audits on our processes and they're all very impressed how we've managed to deploy standard quality control approaches to a material not associated with high volume and repeatability. They recognise that we've gone further – we've incorporated some very high-tech aerospace technologies to our manufacturing. From day one we wanted that, we wanted to deploy aerospace rigour to the way we produce components."*¹³

¹¹ http://www.amtil.com.au/News/AMTIL/Carbon-Revolution---Wheels-of-fortune#.Wt_Ntv7ouUk

¹² <http://www.carbonrev.com/about-us>

¹³ <http://www.amtil.com.au/News/AMTIL/Carbon-Revolution- per centE2 per cent80 per cent93Wheels-of-fortune#.WuHI0ciFPIU>

Assimilation - Post 2010

The company evolved as an independently run research and development program in collaboration with a leading research institution. This developed into a highly focused and effective group of leading engineers, scientists and industrialists within a tightly managed innovation cell. Having the right people in place was imperative. It was no coincidence that each member of the executive team brought decades of knowhow from the aerospace, automotive, and composite industries. They were acers of mechanical and software engineering, business management, supply chain logistics, and assembly. Each placed an emphasis on teamwork, accountability, and communication. Nearly all held a PhD. The company also has numerous formal partnerships for technology development and product testing around the world. This includes Deakin University, CSIRO and RMIT University, each globally recognised institutions in their respective fields of materials sciences and aerospace technology: *"We're not experts in that; we're experts in making wheel structures. That's our core, so when we run into a problem with something like that, like surface chemistry and compatibility of materials and whatnot..."* "Oh, who's the best who can help us here?" and we'd go to the CSIRO Polymers Group and they helped us solve that problem.

The firm developed close relationships with groups such as ITS in Detroit. "They're quite influential in the industry and credible, as well," Dingle says. "The fact that we've been running a lot of our validation with those guys and that they have deep relationships with North American OEMs – and some European OEMs – I think that formed part of the means of communicating what we were doing. It's one thing for us to tell a customer that this technology is real and that it will be validated. But for the party that actually validate their products to communicate that to them is a much different proposition." The firm connected with Ford's global manager for wheels and tires, Dave Rohweder, who, after interrogating the CR team and seeing firsthand what their aftermarket wheels could do, mentioned they should start a project. "He really laid into me," Gass says of the Rohweder meeting. Rohweder directed them to Hermann Salenbauch, head of SVT at the time. *"And then we ended up working on the Mustang. Most automotive programs are small incremental changes. Rarely do you see a platform that has gone from way down in the rankings to implementing this much change. It's a very aggressive and very innovative platform."* The strength of their relationship with Ford is a major reason why it worked. "For something like this to go into a production vehicle environment, it needed to be 120 percent," Dingle says. *"The fact that we worked in a collaborative technical way rather than a supply-a-customer traditional commodity-type supplier relationship ... that really is what we're seeing play out."*

In 2010, the firm presented their prototypes to European and North American car makers and by 2011 they received government funding under the former Federal Government initiative 'Green Car Innovation Fund' that the firm matched that with equity and private capital. This allowed the firm to grow and bring in experienced industry professionals from OEMs and from companies like Ford, CBI (formerly owned by Bosch and Pacifica group) and Boeing. The firm is driven effectively by the CEO building the business around PhD engineers who came up with the initial concept. *"Our aim with the business was to develop a technology that could, in the longer term, be disruptive,"* Dingle says. "If

it's successful as a disruptive technology, it will do to aluminium what aluminium did to steel in the 70s and 80s.¹⁴ The firm commissioned its first commercial production line for a major OEM in 2012. Much of this technological capacity of this line will be used in further development work across the automotive OEM, aerospace and industrial sectors.¹⁵

The motivation to use external knowledge sources is lower than the other firms and one reason could include the intellectual and skilled collateral of the firm's core internal R&D technology capacity and the relatively underdeveloped research program with the University. Unlike firm four, it does not have an internal education research program or innovation strategy explicitly developed with the University. As the details to the ARC research program are unavailable it is understood the research parameters are broad enough to allow for research opportunities to emerge that maximise both the needs of the firm and the University. When the firm was asked about what they hoped to get from contributing funds into the ARC, the one of the co-founders alluded to this issue: *"I don't think we've done a good job of it yet and I don't think we've found it yet, but I think having QS here as another composite manufacturer it makes sense that there'll be things that we can work on together and essentially the costs to each business will be halved. We're not competitors. We don't compete in the same space, so if you think about it from that perspective there's only upside."*

The research arrangements with the current ARC program are loosely structured around broad research goals pertaining to resin development and composite materials processing, particularly for use in carbon fibre wheel technology for both automotive and emerging opportunities in the aerospace sector. Interviewing one of the co-founders about how the University and the ARC research project will help the firm develop further wheel applications he said, *"They will contribute to it by allowing us to learn about materials or a new process or something like that. So they will certainly unlock elements of that, but we wouldn't give the Fibre Hub a project of going and developing an aircraft wheel for CR. That doesn't make sense."* The research may seek to maximise upon immediate research needs that may lead to longer-term research aspirations. The impression is that the firm views the University as a collaborative partner with loosely defined research arrangements, which warrant further development in terms of goals and pursuits of working collectively. There is less clear alignment with this firm and the university role. The existing research program extends to include a few PhD students working on research projects that will contribute to the firm's understanding of processing resin materials and the like. The firm's collaborative partnership with the University seems more project-based, centred on refinement of a specific aspect to the firm's technology advancement, and/or problem-based, focused on identification of solutions to specific issues the firm does not have the capacity (staff or facilities) or time to pursue alone.

¹⁴ <http://connection.vic.gov.au/victorian-wheelmaker-carbon-revolution-gains-traction-after-raising-capital/>

¹⁵ <https://www.compositesworld.com/news/carbon-revolution-reports-first-one-piece-carbon-fiber-wheel>

4.3.2 Realised Absorptive Capacity

Transformation - 2013 Onwards

The firm's transformation of new knowledge and its collaboration with the University and CSIRO allows for the development of internal technological process to achieve production rates to meet the demand of prime OEM markets. This was achieved with establishing its new facility on the University campus supported by government investment. "Our focus is to try and fund it locally, but if we can't do that we will have to seek funding from offshore," The firm's CEO Dr Jake Dingle told The Australian newspaper... *You don't squander a leadership opportunity like this just because you can't get it funded or built locally.*" The company has previously been awarded over \$1.8M through the Federal Government's Green Car Innovation Fund.¹⁶

The firm's technological refinement, particularly of its automated manufacturing processes, has been made possible through continuous innovation driven by firm's design and manufacturing engineering teams, as well as its partnerships with technology driven automakers. It has also collaborated with a local KIBS company Austeng Pty Ltd to specifically design and build machinery to produce their products. *"We do a lot of that internally with some external partners that build the machines for us" such as "People like Austeng, Proficiency Contracting." "Austeng built a curing oven for us; they built an injection machine for us, and a few other bits and pieces."*

Curing Oven for Carbon Fibre Wheel

Our client CR has developed a world first "one-piece" carbon fibre wheel that represents cutting edge in design and manufacture with composite materials resulting in attendant benefits and savings. Austeng assisted in the commercialisation process by developing a convection cure over in high nitrogen/low oxygen environment that provided programmed cure cycle of gradually elevating temperatures over a protracted time period, thereby preventing the resins from discolouring.¹⁷

In November 2013, the Victorian Government contributed \$10 million through the Science Agenda Strategic Project Fund to establish the Australian Future Fibres Research and Innovation Centre (AFFRIC), the \$34 million Carbon Nexus facility, with a new carbon fibre pilot line and research to conduct carbon fibre and materials research. By early 2014 the firm was the first winner named in a program aimed at helping Geelong's manufacturers adapt and has said as many as 300 jobs might be created at the company as it grows. The firm's main international partner is the Ronal Group, one of the world's leading manufacturers of light alloy wheels for cars and commercial vehicles, which has a minority stake in the company (owning one-third of the company) and is the firm's strategic partner and exclusive distributor for the firm's aftermarket wheel products in Europe.

The Ronal Group worked with the firm to launch the first one-piece carbon wheel on the European aftermarket in 2013 that set new standards in terms of weight, performance and comfort and is

¹⁶ <http://www.manmonthly.com.au/news/geelong-could-get-new-carbon-fibre-wheel-factory/> published 30th July 2013

¹⁷ <http://www.austeng.net.au/project/curing-oven-carbon-fibre-wheel/>

already approved for use in Switzerland and the UK. Ronal brings together all subsidiary companies under one roof and makes Ronal Group the corporate brand. As a longstanding supplier to the automotive industry, Ronal Group has a history of strong customer focus, innovation, and quality work and is an ideal partner to take the firm's product globally.¹⁸ The full realised potential of the technology takes time to develop for full commercial applications from exploration to exploitation. Like the fourth firm in this study there is a requirement to legitimise the technology with its supply chain – although the timeframes seeking an OEM approval with a potential end customer and its market does appear to transpire relatively quicker in comparison to the fourth firm.

The firm's research program is focussed on its core patented technology that relates to the design and construction of wheels from continuous fibre, so the strength and stiffness characteristics of carbon fibre are optimised. The firm works with specialist finite element analysis (FEA) partners to develop new and better approaches to accurately modelling the specific properties of carbon fibres. The existing wheels are constructed from continuous fibre and feature a patented bolted joint system that solves the challenges of attaching composites to metals under dynamic loading conditions. The firm's wheel design was required to meet more than 40 design validation program targets right off the bat. These included dimensional tolerances, fatigue tests, structural tests, chemical resistance tests, fit-and-function tests, bolt torque retention checks, and on and on. *"This is the difference between aftermarket parts and us,"* Gass says. Carbon Revolution's uniqueness is furthered demonstrated by its ISO/TS 16949 and ISO 9000 production certifications.

In early March 2014 the firm became the first-round beneficiary of the Geelong Region Innovation and Investment Fund (GRIIF), awarded a \$5Million grant from the Victorian government towards the firm's A\$25M 'smart factory' that opened in October 2015 on the University campus to provide the firm with strong technology production and continual research development with Deakin University. Dingle says. *"It's not like a typical arms' length commercial relationship fortunately. We have very regular contact: people walk out one door and walk down the path and into the facility down the road and talk about specific problems to define what we need to do."* Both Carbon Nexus and CSIRO provide the firm with technology partnerships and services. "If you think about our two key raw materials, resin and carbon fibre, we are now creating a unique set of partnerships to drive forward aggressively with developments in these areas in a way that our future competitors will struggle to replicate. CSIRO have done a lot of work with us on resin chemistry over the last 12-18 months to accelerate our development of systems that perform better both in the product and through the factory. In parallel, Carbon Nexus are now beginning to look at particular forms of fibre and developing different and lower cost or differently performing forms of carbon fibre. It is early stages but we're optimistic that this will develop into something very powerful and unique to our circumstances here in Geelong."¹⁹

¹⁸ <https://www.ronalgroup.com/en/history/>

¹⁹ <https://www.australiaunlimited.com/technology/reinventing-the-wheel-part-two>

Dingle says Victoria has proved a very favourable business environment for the company, thanks to the state's long-standing manufacturing sector. *"There is a strong culture of manufacturing here, and a lot of good skills. Whether its production staff, engineers, logistics – even specialist skills in manufacturing accounting – there are good people available here for the new wave of industry"* he says.²⁰ In August 2015, the Australian Government announced that Geelong will be headquarters of its new \$14 million Advanced Manufacturing Growth Centre (AMGC) to be centred on the emerging carbon cluster industries connected to Deakin University. It will be part of a network of centres across the country and develop a sector competitiveness plan to link local businesses with global companies.²¹

The firm's Geelong facility has the capacity to produce 50,000 units per year, with their current output sitting at about 10 percent of capacity, but the firm has plans for expansion. The company raised new capital of \$50 million in 2016 to fund the current production plant at Waurin Ponds. Mr Dingle said CR will have to raise as much as \$100 million to expand the plant's capacity to 250,000 wheels a year. After that, new plants will be located overseas, closer to customers' car factories, and the local operation will be used as a test bed and as a production site for larger but small-volume wheels for trucks and aeroplanes.²² The firm's CEO Dr Jake Dingle says that once capacity is reached in Victoria, they will be looking to establish offshore facilities to supply large scale OEM programs. Mr Dingle emphasised the importance of keeping research and development as well as maintaining some local production. With its fiercely protected intellectual property, has a strong focus on keeping their cards close, meaning that international expansion will need to be extremely carefully executed.

In interview, the co-founding inventor from the firm indicated that they are maintaining the trade secrecy with respect to their IP and are not open to selling or licensing it: *"...No, we're just commercialising the product that results from that and our IP isn't a machine, it's a whole bunch of things. So we have IP in simply how the wheel attaches to a car, that mechanism is something we patented. We've patented how the spoke with fibres connects to the fibrous rim, the architecture of those fibres and how it all works internally. So we're more focused on IP from a product perspective, that's our edge, and our manufacturing processes to achieve that are more trade secrets than patents. So there's certainly a huge amount of IP there."* For the time being the firm's technology remains relatively closed to cooperative collaborations with others other than its partnerships with the University and Swiss Ronal Group. *"Well, we implement things to produce wheels that no-one's done before, but they're not things that we talk about publicly. And it's not one big machine, it's a number of different process that join together to manufacture a wheel."*

The manufacturing process is said to be highly efficient and controllable, merging the rigor of aerospace processes with the efficiency and control of high-volume automotive production. The full-

²⁰ <http://connection.vic.gov.au/victorian-wheelmaker-carbon-revolution-gains-traction-after-raising-capital/>

²¹ <https://www.australiaunlimited.com/technology/reinventing-the-wheel-part-two> dated 29 Jan 2016

²² <https://premium.goauto.com.au/carbon-revolution-lands-the-big-one/>

scale production lines will be fully automated— human interaction is limited to the supervision of machinery and robotic equipment. Achieving global OEM standards in 2013 for component supply (TS16949) formed part of the overall world class approach to quality and process control. The firm has a *state-of-the-art* Smart Factory,²³ which was purpose-built to manufacture carbon fibre wheels. This facility received ISO certification, allowing the company to become a Tier One supplier to the world's leading automotive manufacturers. The company has forged inwards to larger manufacturing volumes of the carbon fibre wheel technology that is now incorporated into two new Ford model vehicles in the USA from 2015 onwards. The firm continued its success with its wheels incorporated in the mass production of two new US Ford motor being first award a multi-million-dollar contract to supply its innovative carbon fibre wheels for the all-new Ford GT supercar in 2016 with the Ford GT and in 2016-17 for the new Shelby GT350R Mustang.

Exploitation - 2016 Ongoing

Both Carbon Nexus and CSIRO provide Carbon Revolution with technology partnerships and services: *“If you think about our two key raw materials, resin and carbon fibre, we are now creating a unique set of partnerships to drive forward aggressively with developments in these areas in a way that our future competitors will struggle to replicate. CSIRO have done a lot of work with us on resin chemistry over the last 12-18 months to accelerate our development of systems that perform better both in the product and through the factory. In parallel, Carbon Nexus are now beginning to look at specific types of fibre and developing different and lower cost or differently performing forms of carbon fibre. It's early stages but we're optimistic that this will develop into something very powerful and unique to our circumstances here in Geelong.”*²⁴

No one else has a commercially viable competitor to our wheels – it's a challenging thing to design and produce,” says Dingle. The company raised A\$50 million in 2016 to enable the company to expand its production to beyond 50 000 units p.a. and to lower production costs. The firm's CEO acknowledges that 50,000 wheels is small in global terms – one of the company's major strategic partners, Ronal, produces 20 million aluminium wheels a year. The firm is planning for the long term. *“Even aluminium is not on every car,”* says Dingle. *“Aluminium started upsetting the steel apple-cart in the very early 70s. I think now it's around 50-50 on a global scale. The process to derive at each of these milestones has been one of development of the firm's core technology with a variety of actors. It has involved collaborative work with global OEMs, universities and R&D centres such as Deakin and CSIRO. The firm has a production target of 100,000 wheels by 2021. The firm will need to raise up to \$100 million in the future to expand the plant's capacity to 250,000 wheels a year. The agreement with Deakin University allows doubling the size of the facility, “but we'll probably take capacity up by five times through automation and process improvements. For 50,000 parts a year we've estimated 150 people; for 250,000 probably more like 350 people”* Dingle says.²⁵

²³ <http://www.carbonrev.com/technology>

²⁴ <https://www.australiaunlimited.com/technology/reinventing-the-wheel-part-two> - dated 26th January 2016

²⁵ http://www.amtil.com.au/News/AMTIL/Carbon-Revolution--Wheels-of-fortune#.Wt_YTv7ouUk

In support of the firm's production expansion goals, it received \$2.5 million under the GRIFF in support of the production expansion, another financial boost by the Victorian Government to support the region's economic transformation post car manufacturing. The firm has alluded to a possible public listing for 2019 to assist this exploitation plan, and beyond reaching a target of 250, 000 wheels a year, new plants will be located overseas, closer to customers' car factories, and the local operation will be used as a test bed and as a production site for larger but small-volume wheels for trucks and aeroplanes. By early 2017, the company had announced that the advance of its technology and automated manufacturing processes at its Waurm Ponds factory has taken one of the most complex carbon fibre structures ever produced and, in only a handful of years, reduced the retail price by 25 percent. This outcome was made possible through continuous innovation driven by CR's design and manufacturing engineering teams, as well as its partnerships with technology driven automakers.

OEM contracts have expanded to include a third automotive OEM and first European car manufacturer (Ferrari's new 488 Pista supercar) in early 2018 and exploratory NPD for carbon fibre wheel for with an aerospace manufacturer in the first stage of NPD. The firm's CEO said his team was working with Deakin's neighbouring Carbon Nexus facility to improve wheel design and reduce manufacturing costs. He said improved affordability would drive the expansion of his business, not just in the automotive industry, but also in aerospace and industrial sectors: *"There's a lot of technology to happen, and we've got a great team to do it. "It's a very logical technology to take into that (aero) market; the value of weight-saving for aircraft is even more significant for land-based vehicles" he said.*²⁶

²⁶ <https://www.transforminggeelong.com.au/latest-news/95-carbon-revolution-s-25-million-wheel-deal-with-ford-sees-staff-double>

Table 22: Timeline of Firm 3 (CR) Product Innovation Development

AC 1	AC 2 and AC 3	AC 4
<p>2004-2008 Early university research into an automotive carbon fibre wheel technology</p> <p>2015-2020 ARC Research Program contributory funding firm with smaller cluster of SMEs largely based at Deakin University</p> <p>2016 Early exploration of technology for aerospace and application of carbon fibre 'wheels' in other transportation types.</p> <p>2018 New \$15M commercialisation Research Program launched with University & the IM-CRC https://www.carbonnexus.com.au/15m-rd-project-a-good-sign-for-automotive-industry/</p>	<p>2008-11 Early automotive technology development of prototypes for trails in supercar performance cars.</p> <p>2009-2012 International testing and validation to meet and exceed OEM production requirements.</p> <p>Firm adopts disruptive innovation model as first entry to market and combines other knowledge bases such as aerospace science to design and prototype concepts.</p> <p>August 2012 Firm launches carbon fibre wheel for Porsche 911</p> <p>2012-2015 Carbon Fibre Wheels design and produced for OEM client markets</p> <p>2017 ongoing R&D, production expansion and diversification into aerospace sector.</p> <p>2018 New European OEM Carbon Revolution is also working with Ferrari on wheels for the 488 Pista.</p> <p>2018 Commercialisation Research Program launched with University and IM-CRC.</p>	<p>2013 Onwards Achieving global OEM standards for component supply (TS16949) by early 2013 was a key element of the overall world-class approach to quality and process control.</p> <p>2015 ongoing US Ford wheels produced for larger mass production of two vehicles produced in Detroit, USA.</p> <p>2017 ongoing New European OEM Carbon Revolution is also working with Ferrari on wheels for the 488 Pista,</p>

4.4 Firm 4

4.4.1 Potential Absorptive Capacity

Acquisition - 2000s

The innovation behind this firm represents over 25 years of inventive history that involved its 'out-of-autoclave' (OOA) patented technology for curing carbon fibre and composite materials for componentry parts to the automotive, military defence and aerospace sectors. The firm's formation began with an invention in the early 1990s, the outcome of several previous years of prior exploration. The firm came together in 2001 to build upon the technology said to '*revolutionise the aerospace, boat and car building industries by making advanced polymer composite technology affordable*'. The firm established itself by its co-founding inventors as an unlisted company in 2001 based on the patent technology and listed as a public company in 2005. In the exploratory phase prior to 2001 CSIRO undertook trials on the QS process from early 1998 and worked with the firm to define the technology that ultimately lead to the University's involvement from the early 2002s, along with two aerospace companies.

From the firm's inception it sought members of the automotive and marine industries to participate in the development of the process to meet their specific needs. "*Because we can fabricate high quality foam-core composite, the technology is ideally suited to the boating industry, and lightweight honeycomb components find many applications in the auto industry,*" Professor Hodgkin says. Mr Graham inventor and cofounder of the firm said that the environment will also benefit from the technology. "*This process will reduce excessive energy in the manufacturing process, and because it will produce lighter vehicles, it will lead to fuel savings.*"²⁷. As discussed by both Prof Hodgkin and Mr Graham, the patented technology was developed by working together to refine the use of it with a variety of resin materials that involved both basic and applied polymer chemistry and materials science and engineering. The future use of the technology requires continual development, and refinement of the chemistry behind use of different resin materials for various applications: "*This process, along with producing faster curing cycles (to meet customer industrial production volume requirements for different finished products) of various laminates, for a wide variety of geometry, including thin and thick laminates, flat or simple geometrics and, also for three-dimensional complex structures, provides the sources for ongoing research and development investigations with the scientific and engineering community.*" (Prof Hodgkin, 2017).

Assimilation – 2008-2012

During this period, the firm worked with its established global research alliances connected to Deakin University and the VCAMM to collaborate on research into material processing, particularly new chemistry applications and epoxy resins for use with the firm's curing technology. Assimilating the firm's new technology into the business involved migrating potential project developments to their new technology solution to ultimately provide a better-quality part at a significantly lower cost. In 2008

²⁷ <https://www.sciencedaily.com/releases/2001/04/010424073249.htm>

the firm's US partner 'Vector Composites' entered into an agreement for funded R&D, prototype development and production programs by signing a licensing agreement for the firm's patented technology. This allowed the firm to enter North American markets. Vector was awarded a research contract by the U.S. Naval Air Warfare Center (NAVAIR) Division to compare the properties of the firm's new curing technology to that of traditional autoclave processing on one or more qualified carbon fibre 'pre-preg' systems. In 2010, Vector received another grant to assess the use of QS's new curing technology to manufacture composite parts for the international F-35 *Lightning II* Joint Strike Fighter (JSF) program. It was anticipated that the ongoing qualification process of the firm's new technology would take time. The firm held a strategic intent to ensure it can fully exploit the commercial realisation of its technology in conjunction with working with its traditional technology. As the former CEO of the firm explains...

"QS has been actively working on two fronts to secure JSF manufacturing business," Mr Odouard said. "This grant supports our founding strategy, which is to promote the patented QS Process as a viable new technology for the manufacture of high-performance composites such as those required for JSF components. Our parallel and complementary strategy targets specialist manufacturing contracts that can be completed at our manufacturing facility near Fremantle using traditional composites manufacturing techniques such as autoclave."

*"QS has already enjoyed some success in targeting traditional manufacturing contracts for JSF – as demonstrated by the recent Memorandums of Understanding signed with Lockheed Martin, Northrop Grumman and Marand, and this significant teaming with Vector under the Air Force contract now indicates that we are also proceeding well with promoting our proprietary technology," Mr Odouard continued.*²⁸

The firm leveraged its entry into the aerospace and military defence sectors using established traditional autoclave technology whilst exploring and exploiting the use of its new O-o-A curing technology to qualify as a 'Tier-one' OEM supplier to OEM customers or 'primes'. Original autoclave manufacturing operations commenced in 2008 in Perth, Western Australia, later relocated to Bankstown, NSW, to open larger operations in 2013. Evidence of the outcomes of this strategy is a little unclear. One outcome, however, involved the German (Munich) R&D operations relocating to Deakin University, at the Waurn Ponds campus in Geelong in 2015, to work with allied firms and researchers. In late 2011 the firm commenced a joint development project with the German Government and car manufacturer Audi to develop new processing techniques for mass production of automotive parts and in the subsequent year for the OEM automotive market.

The research sought to achieve cost reductions of up to 30 percent over existing manufacturing costs to produce light-weight composite parts for the automotive industry. The ability to rapidly manufacture and cure composite parts to A-Grade surface finish for the automotive industry without the need and expense of traditional autoclaves presents a significant opportunity to the company. The project combined independent composite manufacturing technologies including the firm's Resin Spray Transfer (RST) technology and out-of-autoclave technology. The development of the firm's RST

²⁸ <http://www.aerospacemanufacturinganddesign.com/article/aerospace-manufacturing-design-vector-composites-quicksteps-amd-051710/>

component had an approximate budget of A\$1.2M focussed on building the achievements of RST Development program in Australia, which is due to be completed by May 2012. On one account:

The company is Australia's largest independent manufacturer of aerospace-grade carbon fibre composites and a leader in providing advanced industrial technologies for the global market. Associate Professor Bronwyn Fox and her team have been working with Quickstep in providing validation for the company's cutting-edge manufacturing processes for the production of aerospace-grade composites. *'If our products are to be utilized in the automotive and aerospace industries the technology needs to be validated and tested to exacting standards,'* explains Quickstep's Research and Development Project Manager, Adriano Di Pietro.

The work carried out by Professor Fox and her team has been a vital part of qualifying our technology,' he says. 'We recognise the benefits of collaboration between industry and universities and the opportunities for leveraging the expertise available in the university sector to achieve great results for our customers.' AMCRC has facilitated and project managed the three-year partnership between Deakin and Quickstep (IFM Annual Report, 2012, p.13).

These learning activities represented a major investment by the firm and many other supporting parties, to both the new technology and the benefits of accessing the research facilities at the regional University. The work carried out by the firm with the University and the UK Manchester centre resulted in some early new knowledge documented by the University and discussed in the case study. Some of the other outcomes from this period are analysed further in the case study. Prof Fox states that this firm's technology is embedded in the University, due to the long-standing research projects developed since the early patented technology, including the establishment of the VCAMM and several centres of research in other countries between 2005 and 2008. During this time, several research projects have been funded and undertaken by the university to assist in developing key aspects to the firm's curing technology, namely the chemical processing of materials to cure carbon fibre composites specifically resins.

When asked about how the firm worked with the University on joint research activity to develop its knowledge base, Prof Fox refers to a possible 'disconnect' in its internal knowledge assimilation and management. Several elements of the firm's technology have been subject to several PhD research projects, to the extent that the level of new knowledge is limited. This is partly attributed to change of staff at the company and the university, with loss of organisational knowledge and memory on both sides. This has resulted in fragmented and discontinuous knowledge creation on key elements of the firm's technology, such as the bladder system used in the curing technology. For example, *"one of the projects in the Fibre Hub is a project that Mandy and I finished in 2012. I sat there going, Mandy, why are we doing this again?" "So yeah, there is a bit of a 'disconnect' and lack of corporate knowledge,"* which could be attributed to a lack of internal capacity to absorb new knowledge developed by the University about specific parts of the firm's technology. This seems to be case for the bladder system that the firm's curing technology uses as Prof Fox says... *There's a whole post-doc doing bladder ageing... we wrote a 400-page report on it in 2012...that gets lost in history. "You're going to have a 'disconnect' because there's a loss of corporate knowledge. So, the former CEO Philippe was very hands off when we were doing research and it was Adriano Di Pietro – he has long gone, Jens we worked with a bit. So, there will be a 'disconnect' from 2012 backwards."*

4.4.2 Realised Absorptive Capacity

Transformation - 2013 Ongoing

By 2013 the firm developed and installed its RST technology for automotive application at its Bankstown, NSW location. This new technology, developed in Australia, was partly funded by an AusIndustry Climate Ready Grant. The firm's RST technology in conjunction with its original patented out-of-autoclave curing technology continues to be refined for greater manufacturing capability to make carbon-fibre component parts in less than three minutes. In 2014, the A\$34 million, open-access carbon fibre/composite research facility 'Carbon Nexus' opened at the University's Waurn Ponds campus. With the use state of the art research and analysis labs, pilot scale and research carbonisation lines, and excellent production and research staff, it has enhanced the Greater Geelong region's reputation as an advanced manufacturing hotspot. In 2014 the firm announced that it entered its first agreement to utilise its innovative (RST) technology developed for the automotive industry.

The firm signed a letter of intent with defence contractor Thales Australia confirming the company's selection as exclusive supplier of the bonnet, side skirts and mud guards for the new Hawkei vehicles. In the same year the firm entered into an agreement with its US partner Vector Composites Inc. (Dayton, Ohio), its U.S. licensee, under which QS will integrate its US business interests with that of Vector Composites. As a result, the QS's existing Ohio facility was closed. The firm's executive director at the time, Mr Philippe Odouard, said, *"We have worked very successfully with Vector Composites and believe that this agreement provides QS with an effective sales solution for the U.S. market. Vector Composites will now use QS technology to manufacture carbon fibre parts, and we will maintain our close relationship as Vector Composites showcases our technologies. This enables us to close our U.S. office, which has completed the work for which it was established."*

In 2014 the firm announced its new technology and automotive division will move to the Waurn Ponds campus assisted by a grant of \$1.75 million from the Geelong Region Innovation and Investment Fund (GRIIF). The firm will establish a new R&D facility to design and develop an automotive manufacturing cell to incorporate the innovative QS Process (QPS), which uses liquids to cure components, and the RST system. The relocation represents over a decade of collaboration between the university and the firm and the growing benefits from knowledge creation and exchanges with IFM and the new Carbon Nexus facility. The project complements the creation of a carbon fibre composite cluster with Carbon Nexus and Deakin University, which has a significant involvement in composite research. The cluster is said to be one of only two independent carbon fibre research centres in the world.²⁹

In 2015 the firm delivered its first commercial sale of the QS Process. The contract valued A\$6.2M will use QS's technology to produce large carbon fibre shielding for satellites by Russian satellite

²⁹ <http://www.australianmanufacturing.com.au/23037/quickstep-establish-automotive-division-geelong>

launch company ORPE Technologiya. The firm 'up-scaled' the Qure machine to tailor to its customer's specification to produce larger carbon-fibre parts in order of six metre by four metres to be used to shield satellites during launch. In 2015 saw the firm's new R&D Technology and Automotive Division established at the University's Waurm Ponds campus. Establishing the new site with a budget of \$5.6 million to June 2017 was estimated to create 30 jobs. The relocation deal with Deakin University, the Victorian State Government, involved the firm signing a Memorandum of Understanding (MoU), with terms of agreements that defined key education, research and commercial lease parameters. The three-year arrangement offered the company and Deakin the opportunity to develop critical research pathways, training programs and agreements that would accelerate growth, to the benefit of both parties.

A co-ordination committee involving senior personnel from each party oversaw the collaboration agreement that included a project management group co-ordinating their joint interests. Under the agreement, the firm contributed approximately \$1.75 million over a three-year period for research projects at Deakin. The firm's Managing Director, David Marino, added that QS was *"grateful for the support of Invest Victoria, which joins the Australian government and Ford Australia in helping to progress the establishment of our high-tech automotive and research centre at Waurm Ponds."* Invest Victoria is the Victorian Government's investment promotion arm provided a grant totaling of \$310,000 over a four-year period. This funding is in addition to the previous \$1.75 million provided by the GRIF, an initiative funded by the Federal and Victorian Governments and Ford Australia, announced in November 2014.³⁰

The firm generates up to 80 percent of revenue from the traditional manufacturing technology processes at the Bankstown, NSW. This income stream allows for the firm to operate its new technology R&D department in Geelong, to refine the manufacturing processes and run small carbon fibre composite parts manufacturing to its automotive customers, such as Ford in the USA. New product development of its proprietary technology takes place at the Waurm Ponds site at Deakin University, with expansion of new products with other customers from other markets such as European car manufacturers and a contract to manufacture a light weight carbon fibre structure for a mobile medical X-ray machine. The firm and allied partners were instrumental with pursuing the carbon fibre research facility at Deakin, culminating in the Carbon Nexus facility opening in 2014. The CSIRO's Fibre Processing Team of fibre and material scientists is also located adjacent to Carbon Nexus. Since this time the University and cooperative industries work together to commercialise the wider use of carbon fibre materials in the manufacturing of OEM component parts to the aerospace, automotive and military defence industries.

³⁰ <https://www.deakin.edu.au/research/research-news/articles/quickstep-brings-global-r-and-d-to-geelong>

Deakin is a partner in the newly formed Innovative Manufacturing Cooperative Research Centre (IM-CRC), a collaborative venture between industry, government and researchers in conjunction with the Advanced Manufacturing Growth Centre (AMGC) that forms part of the Australian Governments Industry Growth Centres Initiative. The IM-CRC aims to help accelerate diversification of Australian manufacturing into 'new manufacturing' opportunities and value chains it creates. The IM-CRC operates until mid-2022 with up to \$30 million in funding available to co-fund industry-led research projects. Industry cash is matched on a dollar for dollar basis, where eligible research is conducted by IM-CRC participant universities and/or CSIRO. In kind contributions are also sought, however are not matched with cash from IM-CRC, and nor is capital expenditure funded.³¹

Co-located industry partners include established and developing companies reliant on continuous innovation, which includes firm three and four of this study. The firm's relocation of its automotive R&D activities from Munich to Geelong is contributing to the collaboration between the company's technology programs and is a novel mechanism to align industry needs with areas of universities R&D capacity. As the former managing director David Marino said, *"the company will benefit from access to Deakin University's 'carbon cluster' with its skilled researchers, laboratories and industry networks."* Deakin will be QS's largest research provider. The development of a carbon fibre cluster has been advocated by the University, and all levels of government and allied industry players such as the Geelong Manufacturing Council. This culminated in a strategy document called 'Geelong Economic Futures' (2017).

The strategy is to nurture both local and globally industry research collaborations to develop a deeper carbon fibre value supply chain to leverage from the Carbon Nexus facility and potential production of carbon fibre to industrial volumes to support new and emerging industries locally. Early government support of the Geelong Carbon Fibre cluster landed some initial Federal Government funding support of \$250K in 2016.³² In February 2017 this amount was increased to a total of \$500K by the AMGC to include funding of a NPD project with the firm with an overseas car manufacturer. Speaking with the research manager of Carbon Nexus about their role and collaboration with industry, the professor explains that the university has the capacity to help identify problems with the current technology of the firm. Providing solutions to aspects of the firm's technological processes, in the both the company's Rapid Qure process for curing and the RST for making high quality finishes to carbon fibre light weighted material componentry parts to global OEMs.

Speaking with the Senior Research Manager of Carbon Nexus at Deakin University about their role and collaboration with industry, the professor explains that the university has the capacity to help identify problems with the current technology of the firm and can provide solutions to specific aspects of the firm's technological processes, including the Rapid Qure process for curing and the RST for

³¹ http://imcrc.org/wp-content/uploads/2017/11/IMCRC-fact-sheet_Nov17.pdf

³² <http://www.minister.industry.gov.au/ministers/hunt/media-releases/250000-fund-australian-manufacturing-projects-advanced-composite>.

making light weight composite carbon fibre parts for use in a variety of industries. *“Two researchers are working with CR to investigate next generation materials for automotive wheels and another two are working with QS Automotive to optimise the QS manufacturing process, and the Resin Spray Transfer (RST) process”* he said. The University researches provide complementary scientific knowledge to the firm’s own internal R&D capacity, in addition to access and use of the University’s testing equipment and other facilities.

Specifically, researchers at Carbon Nexus can *“add the resin expertise and knowledge, the processing capacity and ability to choose the right processing technology for the right resin and the right design. It’s all about linking resin selection and/or modification fabrication technology with the design. We don’t necessarily design the component, but you design a mould to suit the component. We bring all those things together and we can make it for them.”* The researchers do contribute to the firm’s early product development works such as prototype projects often in conjunction with the firm’s customer or a firm in their supply chain. *“We’ll, lab scale but pilot scale as well. We would make the first component, well, with them, but we’d give it to them and say, “This is what we can do”.* The Senior Manager continues to briefly explain how the collaborative research relationship with the firm works...*“They are manufacturing engineers. Probably we’re more on the materials side, materials/manufacturing and chemistry, so polymers, bringing the two together, surface interactions between the fibre and the matrix, making the prototype, making the composite.” “We do not any of the scale up, the actual manufacturing of many, many components that they would have to do. We don’t get involved with that.”*

This same manager did make it clear they are not directly involved with assisting the firm to scale its technology to industrial capacity...*“I don’t think it’s our role. It’s not our role to be involved with full scale manufacturing of multiple components or high production rates. They’re manufacturing at a certain production rate. We would want to help them develop the right resins, the right component suitable for a higher manufacturing production, but we wouldn’t actually do it.” “We would say, possibly you should choose this resin, you should choose this process, and I think if you use these materials in this way you should be able to manufacture at this rate.” “But they will be the ones that will go, and do it and they might say, this is the design we want to use.”*

In 2016, several advanced composite projects started that established the firm’s credentials and solution capabilities outside the aerospace sector, which is expected to lead to additional supply opportunities in both the domestic and export markets. These projects include activities with Ford Australia, Thales Australia, Korea Institute of Science and Technology (KIST), DCNS Group (a French naval shipbuilding company and European leader in naval defence), and several other composite end-users. (QS’s Annual Report, 2016). The firm won the Thales Hawkei project development contract to provide individual components from the Geelong operations.

Exploitation - 2016 Ongoing

The firm has struggled to fully exploit market potential of the original patented technology. In so doing, it is evident it has had difficult balancing the firm's resources and time across the two phases of AC. The firm spent many years exploring partnerships across the globe to advance the take up of its patented technology. It established several alliances within Japan, UK, European and USA associated university research centres and industry associates to form centres of excellence to enter into further exploitative projects to get further market traction of its technology. In so doing, it has penetrated the market with large manufacturing contracts with various customers in the military defence aerospace space using its older traditional autoclave technology. This relationship has also enabled the firm to conduct a wide range of exploratory development work in its new technology to prove its technology to large OEM customers such as Boeing and Airbus for lightweight skins and other component parts.

The potential application of its new technology with these global organisations is yet to be realised. Despite continuous exploration of this technology for potential aerospace applications (from 2006), there has been no commercial production innovation outcomes to date. To date, efforts in the US market pertain to the defence aerospace work, which does not involve the firm's new O-o-A technology. The firm forges ahead with this business program, and recently succeeded with securing a new international partnership to access its technology in European markets. The other active market focus for its new technology is the automotive industry and potential new industrial applications occur at Geelong. The firm actively seeks to advance its original and ongoing technology development for new products associated with faster 'out-of-autoclave' curing and processing of light weight composite materials, such as carbon fibre.

The process has evolved to the manufacturing of component parts for the automotive industry (car fenders, car seats, car air ducts) as early exploratory development projects to demonstrate and 'proof' the technology for structures of different geometry and shapes to wider industry use by OEMs. This included the firm's OEM manufacturing contract to produce uniquely designed air ducts used by Ford US. Other projects include a carbon fibre composite car seat working with the University and Futuris. Recently, it has manufactured an exterior casement for mobile X-ray machines being produced in South Australia. This product innovation is completely carbon fibre using the full patented Qure curing process and the new QPS Rapid process. The process includes the full automation of QS curing process and RST technology. This capability reflects the firm's new manufacturing cell that has been established after several years of refinement to implement the outcomes of its most recent manufacturing concept for automotive composite components. This technology is demonstrated through digital imagery.³³

³³ <https://www.youtube.com/watch?v=SNpbI9QWHW8> and <https://www.youtube.com/watch?v=x0Es2pZVeyM>

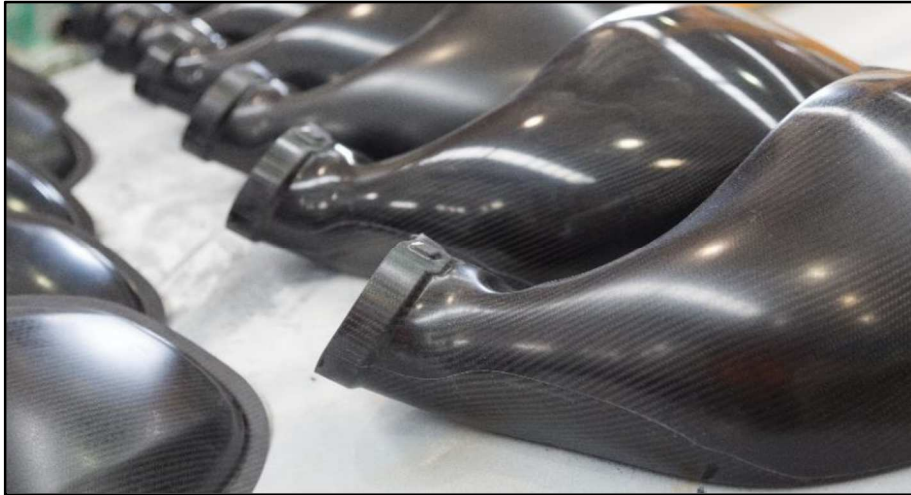


Figure 10: An OEM product developed at the firm's automotive and new technology division in Waurn Ponds site.

Despite the various exploratory product development and process feasibility studies, working with various partners such as Ford, Airbus, Boeing, and Audi, the firm's new technology has not been readily adopted. Its original strategy of selling and licencing its proprietary technology was superseded by a push towards their own full 'fibre to finish' manufacturing process with the development of firm's new QPS. The firm developed from key founding personnel who invented the original patent curing technology, having a strong association and prior knowledge of light passenger aircraft manufacturing. Since 2005, there have been four CEOs and several other executive and senior management changes along with other R&D and technical staff. In 2017, a new CEO joined the firm and the executive team was reduced in size substantially and a revised business operating strategy (2017) has been put into place to focus on three key areas. This new strategy aligns with the firm's investment and belief in the technology – that has awarded the company a partnering deal in early 2018 with an Italian carbon fibre composites group.

The firm took the decision to cease work on the Haweki project after the completion of the final production order scheduled for mid-2018. The project does not fit QS's future growth plans, as the parts are glass-fibre based and do not use our core technologies. The firm decided to it will cease non-core programs that do not fit with its future growth plans as such a new contract with Tasmanian SME Penguin Composites will replace QS as the provider of the Hawkei vehicle's bonnet, side skirts and mud guards. Similarly, at the end of 2017 it was decided to focus R&D Technology development at Geelong that saw the closure of its Munich centre. Throughout 2017 and the immediate future the firm will continue to advance the industrialisation of their Qure and Resin Spray Transfer (RST) technologies for use in the aerospace, defence, marine, automotive and other transportation sectors.

There are further restrictions to the firm's exploitation opportunities with one its major targeted sectors in the form of International Traffic in Arms Regulations (ITAR) that pertain to defence security and intellectual protections required by the US defence industry. Under such conditions the ability for crossover of ideas, team and job rotation of NPD projects are restricted in some senses. As explained by the firm's Product Marketing Manager "As long as you've got a certified autoclave that's

been specifically tested to meet those standards and you've got all the quality certifications and you're ITAR compliant they'll give you the recipe, it says, "This is the material, this is the resin you're using, this is how you make it, you do step one, two, three, four, five, you cure it, you do this, you X-ray it and it goes out". So it's quite a structured, not much scope for change, all you can do is improve your efficiency."

As explained by the firm's Global Production and Marketing Manager, the continued exploration of new knowledge with IFM and Deakin University is a continuous inter-related balance between exploring the technology's advance for product innovation with new clients/customers as new process engineering projects and exploiting the current technology capacity for new engineering product projects with OEMs. The firm's R&D manager, who provides the link with the university, described the role of the company's R&D interest and the nature of the work conducted with the Deakin staff and the current state of the firm's technology in the emerging carbon fibre composites industry sector in Australia. These disruptive processes provide significant value propositions, in terms of cost, process speed and quality to the firm's targeted customers and these technologies are especially relevant to end-users with parts programs in the volume range of up to 30,000 units per annum. As part of the firm's 'fibre to part' or 'fibre-to-finish' process, it has automated its technology capabilities as part of their QPS system.

The innovative industrialisation activities have focussed on development and application of both the firm's Qure and RST technologies to manufacture components for end-users in our targeted industry sectors. The updated 2017 strategy, 'One' QS, includes a revised organisational structure and leadership roles, productivity and efficiency improvements, refocused R&D investment and a focus on targeted business development and growth (QS's Annual Report, 2017, p.20). Over the foreseeable future the firm is targeting several niche volume projects, while continuing to develop and scale-up our next-generation Rapid Qure technology which will provide increased volume capability to enable us to secure larger production projects.



Figure 11: Example of QSs carbon fibre demonstrator product for an OEM

Table 23: Timeline of Firm 4 (QS) Product Innovation Development

AC 1	AC 2 / AC 3	AC 4
<p>Late 1990s-2005</p> <p>Firm patents its technology following its unlisted company public status in 2001. Firms forge R&D collaborations with CSIRO, Deakin University and the VACMM in 2004.</p> <p>2007-2018</p> <p>In-house R&D continues in Munich (Germany) site. Geelong R&D division established at Deakin University in 2015. 2018 Munich operations closed, and transferrable functions moved to Geelong.</p> <p>Late 1990s-2005</p> <p>First of many larger OOA curing plants developed to scale and R&D university research centres at Deakin, and other universities in the UK, Germany, Japan and USA.</p>	<p>2005-2008</p> <p>Global research partners with several other universities that forged research connections to Deakin University via the VCCAM – end 2012</p> <p>2009-2013</p> <p>Qualifying projects in conjunction with its US strategic allied partner Vector undertakes process qualification testings to meet sector standards. RTS achieves OEM recognition in joint research project. Sale and licensing of technology to two external global customers.</p> <p>QPS - Growth Opportunities</p> <hr/> <p>» Quickstep Production System (QPS)</p> <p>QPS is an advanced lean production system, complete material to finished part solution</p> <ul style="list-style-type: none"> - Proprietary technology - R&D initiative based in Geelong - Multiple market and part applications <p>» Typical applications include: -</p> <ul style="list-style-type: none"> - Micro-X (portable x-ray device) <ul style="list-style-type: none"> - Carbon fibre chassis using Qure process - Establishes higher volume capability - Global market - Front Fender (automotive) <ul style="list-style-type: none"> - Demonstrates capability for automotive and aerospace - Addresses rate needed and part complexity - For European luxury automotive manufacturer 	<p>2014-onwards</p> <p>Technology exploitation of firm’s appropriated knowledge through product development demonstrator projects with European/US automotive OEMs.</p> <p>Ongoing external partnerships including the recently announced that we have signed a Manufacturing Partnership Agreement with ATR Group, a leading Italian company that designs, prototypes and manufactures structural parts and components in advanced composite materials.</p> <p>2016</p> <p>Completed OEM contract with Ford US partially use of firm’s technology.</p>  <p>2017-18</p> <p>Completed use of QPS technology with Micro-X-ray carbon fibre exterior body shell.</p>

4.5 Antecedents of Firms Absorptive Capacity

4.5.1 Antecedents of Firm's Absorptive Capacity

This section discusses relevant aspects of the AC literature reviewed, the data analysis from the case study to inform conclusions on the role of antecedents to a firm's AC. This will bring together the following to reflect the framework envisaged in the methodology:

- AC learning dimensions (Zahra and George, 2002);
- AC antecedents (Volberda, et al; 2010); and
- Internal or external AC capabilities (Lewin, et al., 2011).

The taxonomy developed by Lewin, et al., (2011) enables both the four AC learning phases of Zahra and George (2002) and the AC antecedents of Volberda, et al; (2010) to be grouped broadly under two firm capability components, those being the internal and external AC capabilities (Lewin, et al., 2011).

A review of the literature indicates AC antecedents are predisposed to either exploratory and/or exploitation learning stages, apart from managerial conditions that transcends all AC learning phases. Similarly, internal and external AC capabilities reflect this same dichotomy. The meta-routines identified for each type of capability are split similarly, with exception of two that integrate both capabilities. By adopting Lewin, et al., (2011) configuration of meta-routines that underlay these two capabilities, the study's findings can be framed in terms of either type of capability, according to AC learning phase and dominant influencing antecedents. Internal AC capabilities pertain predominantly to the dominant antecedents of assimilation and transformation, whilst external firm capabilities pertain to antecedents of acquisition and exploitation - broadly differentiated in the table below. This methodology is consistent with Lewin's, et al., (2011, pp.85-86).

Internal AC meta-routines involve the regulation of activities related to managing internal variation, selection, and replication (VSR) processes. They include contextual organisation-specific routines (formal and informal) for *facilitating variation* and enabling the emergence of new ideas within organisations, for selecting ideas for further development (*design of selection regime*), for *sharing and combining knowledge and superior practices across the organisation*, and routines for *reflecting on, updating, and replacing old practices*.

External AC meta-routines follow the tradition of extant models of AC, and Zahra and George (2002) which focus on the acquisition and utilisation (exploitation) of knowledge from the external environment but overlook the role of AC for generating new knowledge internally. The external AC meta-routines include routines for *identifying external knowledge* and routines for *learning from and with external organisations*. Lewin, et al., (2011, pp.85-86).

A framework has evolved from the established literature/research where internal and external capabilities are the configuration of several meta-routines as shown in tables below, from Lewin, et al., (2011). When AC is viewed in the context of a 'dynamic capability' there is a raft of internal and external capabilities (Lewin, et al., 2011) that pertain to a firm's innovation performance and outcomes. This lends itself to the framework of Volberda, et al., (2010) and explored further by others to extend to the theory of dynamic capabilities (Eriksson, 2014). Examining differing effects of organisational antecedents on Potential and Realised AC would not only clarify how AC can be

developed, but also reveal why firms have difficulties in managing AC successfully. Furthermore, clarifying a firm's AC across internal and external capabilities represents an important method to identifying a dynamic capability for a firm. AC informs and can mediate a firm's dynamic capability; it is a precondition to a potential suite of dynamic capabilities. One of these dynamic capabilities is a firm's **innovation capability** – as examined by its internal and external dimensions across several antecedents.

Table 24: AC Antecedents, Learning Phases and Innovation Capabilities

AC Antecedents	AC Learning Phases				AC Firm Innovation Capabilities	
	AC 1	AC 2	AC 3	AC 4	Internal	External
1. Intra-organisational	○	●	●	○	√	
2. Inter-organisational	●	○	○	●		√
3. Prior related knowledge	●	●	○	○	√	
4. Business conditions	●	○	○	●		√
5. Managerial conditions	●	●	●	●	√	√
AC Firm Capabilities						
Internal		√	√			
External	√			√		
● Dominant antecedent			○ Supporting antecedent			
AC Firm Internal Capabilities √ <ul style="list-style-type: none"> Facilitating variation; Managing internal selection regimes; Sharing knowledge and superior practices across the organisation; Reflecting on, updating, and replacing old practices; and Managing adaptive tension 			AC Firm External Capabilities √ <ul style="list-style-type: none"> Identifying external knowledge and routines for learning from and with external organisations; Learning from and with partners, suppliers, customers, competitors, and consultants; and Transferring knowledge back to the organisation. 			

Author's own compilation based on the work of Zahra and George (2002), Volberda, et al; (2010) and Lewin, et al., (2011).

4.6 Firm AC Antecedents Analysis

4.6.1 Antecedents of Acquisition

Pursuant to literature on AC antecedents (Volberda et al., 2010) both managerial conditions and inter-organisational learning are factors to acquiring new knowledge from external sources. In terms of inter-organisational factors Lewin, et al; (2011) identified the following external AC routines:

In terms of inter-organisational factors Lewin, et al; (2011) identified the following external AC routines:

1. identifying and recognising value of external knowledge and routines for learning from and with external organisations;
2. learning from and with partners, suppliers, customers, competitors, and consultants; and

3. transferring knowledge back to the organisation.

All firms engage in ‘joint knowledge creation projects’ (AC1.2) as the most likely business practice followed by ‘openness and recognition towards external knowledge sources’ (AC1.1); ‘motivation to use external knowledge sources’ (AC1.4); and ‘identification of new knowledge in external sources’ (AC1.5). This is a frequent pattern for all firms across the acquisition learning processes for acquisition of knowledge with minor exceptions for firm three. All firms in the case study highly value the process of joint knowledge creation due to the success they have achieved with prior experiences with the University. This success is measured by a range of product innovations released to a firm’s market achieved through the NPD process.

Table 25: Frequency Ranking of Coding Results - AC 1 Acquire

AC 1 Acquire Code	Firm 1	Firm 2	Firm 3	Firm 4	Total Firms
AC1.2 Engagement in joint knowledge-creation projects	1 st	1 st	1 st	1 st	1 st
AC1.1 Openness and recognition towards external knowledge sources	2 nd	2 nd	2 nd	2 nd (equal)	2 nd
AC1.4 Motivation to use external knowledge sources	3 rd	3 rd (equal)	5 th	2 nd (equal)	3 rd
AC1.5 Identification of new knowledge in external sources	4 th	3 rd (equal)	4 th	4 th	4 th

Firm 1

1. Identifying external knowledge and routines for learning from and with external organisations;

The first firm’s ability to acquire knowledge is largely dominated by the learning processes consistently undertaken by all the firms. This firm relies on the University as a source of new external knowledge as it has no internal R&D capacity other than operational staff. The source of new knowledge that informs NPD is a relationship developed with their main suppliers such as the textile fibre company DuPont and manufacturers of textile fabrics and the University. The firm’s results are marginally lower when compared to both the average and percentage results for all firms combined; however, its result for ‘motivation to use external knowledge sources’ (AC1.4) and ‘acquisition of knowledge through various sources’ (AC 1.7) are above the total percentage scores for all the firms.

The firm spent several years sourcing new knowledge from different testing laboratories in the UK. The firm’s prior knowledge reflects its learning activity through ‘acquisition of knowledge through various sources’ (AC 1.7) and ‘selecting and retaining knowledge from external sources’ (AC 1.8), which was proportionally higher than total average for the combined firms. This represents the early exploration efforts the firm undertook to derive its knowledge and technology bases. The firm has benefitted largely from a variety of external knowledge sources, such as oratory testing at Cambridge University and secondly with a private testing facility in the UK. It was also heavily reliant on knitting machine technology acquired in the US. The recognition of the value of scientific testing and continual R&D reflects in the value captured by the firm since 2010. This value is captured in the firm’s successful product innovation outcomes with its first industry standard recognised product in 2010

at CE 1 Level. This was followed by another product that achieved the highest level of personal clothing protection standard of CE 2 Level in 2013. At the end of this successful period the firm was introduced to Deakin University through a Federal Government initiative.

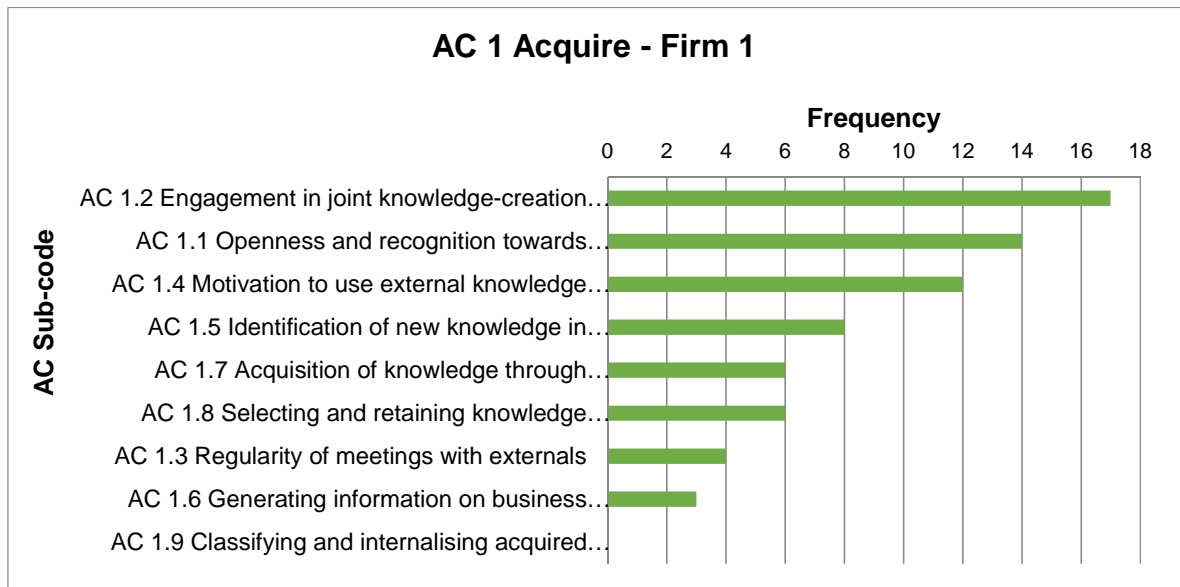


Figure 12: Example of Frequency Patterns - AC 1 Acquire

2. Learning from and with partners, suppliers, customers, competitors, and consultants

The firm had an early mover advantage with the assistance of a leading industry UK private consultant that acted as a technology scout ('gatekeeper'). A 'learning by doing' manner working with its tight supply chain developed a preferential recognition with the DuPont Company. Achieving this success and developing its technology knowledge lead to extending its knowledge search to work with the University from 2013. Its collaborative learning relationships are less formal when compared to the other firms, with less reliance on the use mechanisms such as contracts, memorandums of understanding (MoUs), teaming arrangements, and other formal partnerships.

3. Transferring knowledge back to the organisation

It was not till 2013/14 that firm developed its collaboration with Deakin University to add value the firm's earlier prior knowledge sources. The firm does not appear to strategically seek other sources of knowledge to expand its product innovations. The firm has established a first entry/early mover advantage of securing strong support with its relationship with one of its main fibre suppliers (DuPont Company). DuPont has indicated it would give the firm early access to new fibre technology it is currently developing. This relationship developed from the firm's well-regarded reputation with its authentic use of the fibre technology. DuPont rated the firm's innovative use of their fibre technology amongst its top 50 preferred customers. Furthermore, collaboration between the University and the firm has developed research network ties with DuPont. Meetings have transpired between the University and DuPont researchers on possibilities of future collaborative work.

Firm 2

1. Identifying external knowledge and routines for learning from and with external organisations;

The firm has largely benefitted from acquired knowledge developed by the University to jointly develop a research program to industrialise the technology for commercial applications. The firm worked with the University and the spin-off company (Cytomatrix) to subsequently refine this technology to industrial scale for commercial applications. This technology is now patented. Its potential achieved with the first realised commercial exploitation achieved by two product innovations released to the firm's markets in 2016 and 2018. This firm's top responses include (i) 'engagement in joint knowledge-creation projects' (AC 1.2); (ii) 'openness and recognition towards external knowledge sources' (AC 1.1); and (iii) 'motivation to use external knowledge sources' (AC1.4). These are consistent with the total averages for all firms, with 'identification of new knowledge in external sources' (AC1.5) rating as equal third top response with AC 1.4. The firm's results across the following three learning processes; 'regularity of meetings with externals' (AC 1.3); 'generating information on business environment relevant to new business opportunities' (AC 1.6); and 'selecting and retaining knowledge obtained from external sources' (AC 1.8) is above the combined firms' average. The regularity of meetings with the University are a direct result of a formal joint research agreement between the firm and the University with Cytomatrix Pty Ltd to develop the short polymer fibre (SPF) technology and a \$2M joint research program with Deakin to develop original Deakin technology.

2. Learning from and with partners, suppliers, customers, competitors, and consultants

The transformation of the new knowledge into the firm's knowledge based was assisted by \$1.2M grant from Federal Government under the Next Generation Manufacturing funding program. Firm two benefits from a history built since 2005 by its parent company in Switzerland. It has a wider technological focus with diverse product applications. It has a legacy of proven commercially accepted uses of its technology across diverse customer base and markets that apply textile treatments to various finished products. The Australian subsidiary firm developed its patented technology from its licensed use of the original 'proof of concept' technology created by the University with two other parties in 2014.

3. Transferring knowledge back to the organisation

The firm built upon its prior knowledge initially by acquiring new knowledge and technology through its licensed IPR and has subsequently advanced its own IPR in collaboration with the University. The acquired knowledge informed a new technology platform that produced the firms first two product innovations released in 2016 and 2018. The application of the firm's new technology has diverse commercial is marketed for commercial applications to wide range of textile and clothing manufactures across the world.

Firm 3

1. Identifying external knowledge and routines for learning from and with external organisations

This firm reflects an organisation that is open to sourcing new knowledge to address internal knowledge shortfalls, specifically when solving a business problem unresolved from the application of its own internal capacity. The firm cites on several occasions where it has relied upon the assistance of external knowledge support. This support includes the University itself and wider networks. However, it is less motivated to that of the other firms. . Unlike the other firms, 'motivation to use external knowledge sources (AC 1.4) is ranked fifth just a few scores above 'identification of new knowledge in external sources' (AC 1.5). Acquisition learning processes of 'engagement in joint knowledge-creation projects' (AC 1.2) 'openness and recognition towards external knowledge sources (AC 1.1) and 'acquisition of knowledge through various sources' (AC 1.7) are the firm's top three most frequently coded sub- spots, which is a sharp contrast to the other firms. As mentioned earlier, the third firm varies marginally with its learning processes associated with AC 1 acquisition.

Strategic and targeted acquisition of knowledge through various sources stands out for this firm. The firm will speak with and search extensively across existing and new networks to support the progression of its carbon fibre wheel technology for wider commercial applications. The firm's acquisition of knowledge through various sources (AC 1.7) is aptly expressed by the firm's CEO...

*"We will go to the ends of the earth looking for cutting-edge technology; things that give us ... an advantage over our competitors, and that's exactly what things like carbon-fibre wheels do," he said. "It wasn't an easy road ... but I can tell you I was extremely impressed with the tenacity of the team here at CR. If we failed a test on Monday, we would have a solution on Friday. "That's the kind of tenacity you need when you're treading new ground and making something the world has never made before."*³⁴

2. Learning from and with partners, suppliers, customers, competitors, and consultants

The firm does rely on external sources for its new knowledge, but it appears less driven to search for a diverse range of external knowledge sources. A brief explanation for could be due to the nature of the firm's own internal R&D capacity, since it is made from diverse skilled staff with global automotive engineering, technology production and industry experiences. It seeks to select and obtain knowledge through reputable sources as the third most frequent learning pattern, followed by identification of new external knowledge sources through a vetting process. The engineers went on a spree, vetting the globe's who's who of resin and composite suppliers, and as it happened, Carbon Nexus, one of the world's foremost carbon-fibre manufacturers, was also based at Deakin University along with a top resin creator, in the form of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The proximity of this group of three has allowed for the quick refinement of the firm's proprietary formulas and architectures.³⁵

³⁴ <https://www.transforminggeelong.com.au/latest-news/95-carbon-revolution-s-25-million-wheel-deal-with-ford-sees-staff-double>

³⁵ <http://www.motortrend.com/news/carbon-revolution-rethinking-wheel-aussie-style/> published 14/12/2015.

3. Transferring knowledge back to the organisation.

As such, the firm operates on a more 'closed' or *self-reliant* innovation system business model, which could be largely due to secrecy problems associated with its patent technology. When the firm needs new knowledge, they seek to identify an external source and selectively will work with them in an inclusive dyadic relationship to transfer knowledge back to the business internal engineering and production operations.

Firm 4

1. Identifying external knowledge and routines for learning from and with external organisations;

The top frequently coded sub-codes for this firm includes (i) 'engagement in joint knowledge-creation projects' (AC 1.2), (ii) 'openness and recognition towards external knowledge sources (AC 1.1) and (iii) 'motivation to use external knowledge sources (AC 1.4) and 'identification of new knowledge in external sources (AC 1.5), which is consistent with the average total scores for all firms. However, AC 1.2 and AC 1.1 results are lower than the either the average and/or percentage results for all firms combined. The firm's responses to AC 1.4 'motivation to use external knowledge sources' is much higher than the average for all firms, indicating strength lies with this activity. This would resonate with the exploratory efforts the firm undertook between 2005 onwards with a deliberate effort to reach out to carbon fibre and composite materials processing research centres across the globe, with up to six different allied industry and university research centres undertaking R&D with the firm's new curing technology and machinery.

This firm spent many years during the exploratory stage with a diverse group of potential knowledge sources across the globe. Few of these early relationships appear to exist today, and whilst some assisted the firm in its global efforts to secure OEM contracts, this has been largely restricted to its application with the firm's older traditional technology. The top frequently coded sub-codes with the highest representation for this firm, which are above the average for the combined firms are 'generating information on business environment relevant to new business opportunities' (AC 1.6); 'selecting and retaining knowledge obtained from external sources' (AC 1.8); and 'classifying and internalising acquired knowledge' (AC 1.9). The firm has an extensive R&D department that forms one of the three tiers to its current business strategy with a vast array of internal capabilities.

The firm works with the University on material processing such as resin developing for curing. It requires continue exploration of knowledge through process development projects with potential customers to lower the curing timeframes. The firm aims to demonstrate that its technology can reach a desired structural quality and integrity at the production volumes required by many global OEMs. As discussed with the firm's executive Global Business Manager, the firm has relinquished its earlier developed networks. The firm's links with US and Europe universities has declined that predominantly linked to its German facility. Since the interviews conducted for this study the firm has

also disbanded its R&D German facility. The remaining research programs linked with German universities are to be absorbed with the local Geelong R&D operations by end of 2018.

2. Learning from and with partners, suppliers, customers, competitors, and consultants

This firm spent many years during the exploratory stage with a diverse group of potential knowledge sources across the globe. It is understood that such collaborations and alliances with global research centres has allowed for incremental improvements with development and processing of the chemical properties of materials such as resins for faster curing times, better quality finishes and wider market applications in the fields of aerospace, automotive, defence/military land and aircraft. Ultimately the firm's technology seeks to improve the curing times of carbon fibre and composite materials. Within the industry a curing time of one minute or less is the benchmark figure that needs to be cracked to propel the firm's technology to wider commercial industry applications. It is unclear how this will be achieved; other manufacturers are having said to achieve this with different curing technology.

3. Transferring knowledge back to the organisation

This firm spent many years during the exploratory stage with a diverse group of potential knowledge sources across the globe. Evidence collected does not clarify how and the extent to which the global collaborative work informed the firm's advancement of its technology in the NPD outcomes. The work carried out by the firm with the University and the UK Manchester centre resulted in some early new knowledge documented by the University and discussed in the case study. Some of the other outcomes from this period are analysed further in the case study. The firm's innovative patent technology is yet to create large commercial inroads to their targeted markets. It is unclear if the initial exploratory efforts of this firm were too widely distributed to manage the R&D investment effectively; or if the firm's resources allocated to manage the potential knowledge creation and exchange process were too thinly spread to benefit from these relationship networks.

4.6.2 Antecedents of Assimilate

The least dominant AC for all firms is assimilation. Assimilation refers to the firm's processes and routines that allow it to analyse, interpret and understand the knowledge obtained from external sources. Assimilation is important to ensure the acquired knowledge is spread through the business to enhance organisational learning and memory and to build upon prior knowledge. Assimilation processes are the weakest identifiable learning dimensions of the AC concept amongst all firms and these pertain to a firm's intra-organisational AC antecedents or internal practiced micro-routines or meta-routines discussed in length (Lewin, et al; 2011, Peeters, Massini and Lewin, 2014, Feldman, et al; 2016). Intra-organisational antecedents which are embedded in the internal micro-routines identified by Lewin, et al., (2011) include:

1. Facilitating variation;
2. Managing internal selection regimes;
3. Sharing knowledge and superior practices across the organisation;
4. Reflecting, updating, and replicating; and
5. Managing adaptive tension.

There are distinct individual differences across the firms with little consistency between the firms across the sub-nodes. Only the fourth firm reflects the total average for all firms. The top frequency patterns for all firms across the assimilation learning processes include (i) 'integration of new knowledge into firm's knowledge base' (AC 2.3); (ii) achieving collective understanding of the acquired knowledge (AC 2.2); (iii) 'disseminating new knowledge throughout the firm' (AC 2.4); and (iv) 'discussing the acquired knowledge' (AC 2.1).

Table 26: Frequency Ranking of Coding Results - AC 2 Assimilate

AC 2 Assimilate Code	Firm 1	Firm 2	Firm 3	Firm 4	Total Firms
AC 2.3 Integration of new knowledge into firm's knowledge base	1 st	2 nd	1 st	1 st	39 - 1 st
AC 2.2 Achieving collective understanding of the acquired knowledge	3 rd	1 st	2 nd	2 nd	33 - 2 nd
AC 2.4 Dissemination of new knowledge throughout the firm	2 nd	4 th	4 th	3 rd	19 - 3 rd
AC 2.1 Discussion of the acquired knowledge	5 th	3 rd	2 nd	3 rd	16 - 4 th
AC 2.5 Using tools for spreading knowledge throughout the firm	4 th	5 th	5 th	5 th	5
Single firm totals	31	40	13	28	112
Single and Total Firm Averages	6.2	8	2.6	5.6	22.4

Without overtly alluding to such internal practices, a few observable patterns have been identified across each firm from the data collected. The first two smaller firms have the highest responses that can be attributed to this learning process. This would account for the nature of the innovation changes that are incremental to its core business products. As knowledge is often sourced by key individuals acting in 'gatekeeper roles' they act as boundary spanners at the interface between firm and its external boundaries to bring assist knowledge transfer into a firm (Cohen and Levinthal, 1990). They are conduits for knowledge distribution within the business that cross boundaries of various external networks. The network position and its centrality with ties outside the organisation is the critical aspect to boundary spanning to manage tacit knowledge that is largely embedded in people. To assimilate knowledge requires regular interaction between staff and the external source to exchange and stimulate new combinations of knowledge. This can bring new findings into the business operations, processes and ultimately product innovations.

Firm 1

The most frequent responses for this firm included (i) 'integration of new knowledge into firm's knowledge base' (AC 2.3); (ii) 'dissemination of new knowledge throughout the firm' (AC 2.4); and (iii) 'achieving collective understanding of the acquired knowledge' (AC 2.2) represent the top responses for firm one. The first two sub-codes 'integration of new knowledge into firm's knowledge base' (AC 2.3); and 'dissemination of new knowledge throughout the firm' (AC 2.) are above or higher than the total average for all the firms.

1. Facilitating variation

Assimilating external knowledge to the business to develop its product development is attributed to opportunities arising from the firm's industry affiliations and networks. These networks allow for continuously incremental improvements to its product range through scientific testing and technological research advancements. Variation of its products is a result of creative new designs combining the latest technology and knitting manufacturing know-what and doing. The codification of such knowledge is limited, with product development expertise and knowledge embedded in individuals involved in the process – that is tacit knowledge.

2. Sharing knowledge and superior practices across the organisation.

The firm benefits from selectively sharing its tacit ('know-how') internal knowledge that is captured in its heavily protected intellectual property, and its common working trade knowledge of new product developments within its immediate networks. This is shared as an iterative process when required with the University through laboratory testing regimes, informal instructions and design improvement modifications that occur within its tight network. New knowledge developed in this learning process is subject to research articles published by the University, subject to consent from the firm and tight parameters to the firm's IP. There has been interaction between university staff and the business operations, allowing for insights to be gain 'first hand' by researchers to the business practices and routines. A University research team member is embedded in the business that has allowed the transfer of both tacit and working knowledge between the firms and University researchers. The firm has maintained a high-quality protective clothing standard from the outset and continues to monitor and ensure compliance with these standards. Despite the recent relaxation of European protective clothing design standards, the company has not compromised on its quality.

3. Reflecting, updating, and replicating

It leverages from a highly quality, competitive cost and value for money product. Its ongoing relationship with the University has been able to scientifically prove its safety credentials with use of analysis of the reduction of 'soft tissue' injury to a person because of its product protective quality. The firm excels with incorporating incremental new knowledge acquired from its laboratory testing into new prototype knits achieved by working with its knitting manufacturers. This process has been a two-way iterative process of *'trial' n' test'*; involving a learning by doing process until the desired textile quality is obtained.

4. Managing internal selection regimes

The firm's ability to reflect, update or replicate its routines is achieved with regularly tacit exchanges between the firm's staff, university researchers, and operators at the different manufacturing plants. Whilst this internal learning process is not dissimilar to other firms, it is more overt, less formalised, and timely to ensure new products reach markets for launch into new fashion seasons. The product design is as much about the science as it is about the fashion. It has its product range for a broader European/UK market appeal and a more tailored and specific US market branded under a different name.

Firm 2

1. Sharing knowledge and superior practices across the organisation; and Reflecting, updating, and replicating

The top responses for this firm include (i) 'achieving collective understanding of the acquired knowledge (AC 2.2); (ii) 'integration of new knowledge into firm's knowledge base (AC 2.3); and (iii) 'discussion of the acquired knowledge' (AC 2.1). AC 2.2 and 2.1 activities are well above the total average for all the firms. Discussion of the acquired knowledge stands out for this firm above that of the other firms and this is attributed to the co-location of the firm's Australian R&D executive manager on campus, which encourages daily regular interaction. This was important during the last two NDP phases to assist the industrial commercialisation of the technology for new product outcomes, released in 2016. The finding for this learning activity is consistent with its response to AC 1.3 – regularity of meetings with externals – which stood out from the other firms when acquiring knowledge from their university partner. In the early exploration phase, the firm placed a strong emphasis on working very closely with Deakin University to commercialise the earlier technology developed by the University in collaboration with the original industry partner (Cytomatrix Pty Ltd). This initial contact instigated the seeds to a joint venture in November 2014; an arrangement that is entering its third year to include the development of a successful technological platform to manufacture short polymer fibres. The university has been strategic with developing its capabilities with industry, highlighted by its strategic business plan setting out the research direction to 2018.

2. Facilitating variation; and Managing internal selection regimes

Not dissimilar to firm one this firm's ability to assimilate new knowledge into the business – has been able to take newly acquired knowledge from the University to further refine its technology for commercial industrial applications. The scale-up process has been achieved in a relatively short period, with an initial product release in 2016. The second firm's ability to acquire the early technology developed by the University stems from a compatible knowledge bases between the firm's internal R&D capacity with the University researchers and spin-off co-creators. The firm's response to 'achieving collective understanding of the acquired knowledge' (AC 2.2) indicates the role of social relational capabilities that builds upon cognitive and social proximity dimensions, particularly trust and alignment of similar and complementary knowledge bases. As the firm's executive said...*"I got along really well with them and basically it was the right place, right time where this technology was just starting to be applied in some areas, particularly biomedical areas, and I came along with the HQ background and had a conversation that we can help each other bring this technology through."*

When discussing the collecting learning processes the firm has developed with the University the executive manager highlights the collaboration arrangements it entered to assimilate new knowledge and technology it's the firm's knowledge base. *"The background at that point in time, so when we first made contact, is that we then built up two levels of collaboration. One was very focused on a multi-year research program with Deakin and that was between HQ Australia and Deakin University. So, we moved forward with the research program looking at different materials within this class of ingredients, developing basically the start of the product pipeline.* By using the acquired new

knowledge the firm developed its operational phase of the research program as explained. *“The other part of the program was operational and that was tasked with building up the scale-up capability for the technology and moving that forward into commercialisation.”* The firm’s ‘Real Silk’ product is just one product and a pipeline product, *“so that’s just the starting product launched as a result of the technology developed at Deakin.”* The firm has successfully designed and built its up-scaled synthesis pilot machine directly between HQ Australia and Deakin.

Firm 3

1. Sharing knowledge and superior practices across the organisation

Firm three is consistent with the overall average patterns, to reflect the patterns of learning of the larger two firms in this study. The firm has a strong regard for the use of internal tools to monitor and record the capture of knowledge diagnostics; this reflects the strong dominance of engineering training by the original firm creators and its quality ISO practices. Firm three records ‘integration of new knowledge into firm’s knowledge base (AC 2.3); ‘achieving collective understanding of the acquired knowledge’ (AC 2.2); and ‘dissemination of new knowledge throughout the firm’ (AC 2.4) as the top three sub-codes across its assimilation activities. The firm has a strong regard to internal tools to monitor and record the capture of knowledge diagnostics.

The firm’s original creators have incorporated knowledge throughout the firm with internal training of staff, whilst specialised staff has been specifically sought. *“Our Manufacturing Director’s name is Greg Lindsay and he came from Bosch and previous to Bosch was at PBR (Pacifica Brakes). So he was involved in setting up factories in the US, Thailand and China for making millions of brake callipers and brake rotors every year. That very established manufacturing philosophy of how you manage a project for an automotive customer from beginning to end and manufacture products and delivery, that’s his core competency.”* Greg is the Manufacturing Director, with a number of staff under his helm.

“So we combine that grey hair, essentially, with composite technologies and our core technologies to get to where we are today.”

The firm applies secured quality ISO practices and raft of other industry accreditations. The firm highlights this with its responses to the interview and accounts – an interview transcript is shown below. The firm identified it uses a variety of tools for spreading knowledge throughout the firm (AC 2.5). This was a standout feature for this firm and was proportionally higher than the other firms’ responses. This is attributed to clearer accounts to its internal knowledge management process. When the firm was asked specifically about this a detail break down of internal capabilities in terms of routine practices is discussed. *“We have management procedures, we’re ISO9001 certified, TS16949 certified, so everything follows a defined process, whether it’s technology development or program management or whatnot. There are a lot of things that come into that, so the lead document might be a CNPI we all it which is Change and New Product Implementation project....So we’ll have*

a CNPI for a new automotive program, weekly meeting, all the actions defined, a timing plan that sits next to that and what-not. We have a full structure set up for that.” . These are some of the firm’s routine practices for project management built up over time.

Firm 4

1. Sharing knowledge and superior practices across the organisation; and Reflecting, updating, and replicating

The fourth firm’s results are consistent with the results of the total average of all firms that being (i) ‘integration of new knowledge into firm’s knowledge base (AC 2.3); (ii) ‘achieving collective understanding of the acquired knowledge’ (AC 2.2); and (iii) ‘dissemination of new knowledge throughout the firm’ (AC 2.4); the remaining results are weaker in relation to the combined total averages for the firms. As such, the firm appears to show a weakness in these areas. The firm works with the University on material processing such as resin developing for curing purposes. It requires continue exploratory of knowledge to lower the curing timeframes to demonstrate its technology can reach production volumes, structural integrity and quality finishes of parts required by for many global OEMs. The firm’s approach to technology development in support of new product developments tends to be either evolutionary or reactionary to a commercial opportunity; exploiting technology and making innovation work; and seeking or adapting existing technology solutions to minimise the high levels of cost and risk involved in exploring its new technology.

It is not clear how the multiple global research networks informed the firm’s advancement of its technology in the NPD outcomes. However, the principal goal intended from these networks of composite centres is to explore commercial applications of the firm’s technology and prove that it works for commercial exploitation in diverse markets. It is understood that such collaborations and alliances with global research centres has allowed for incremental improvements with development and processing of the chemical properties of materials such as resins for faster curing times and improved quality finishes that would appeal to a wider market audience in the fields of aerospace, automotive, defence/military land and aircraft. Managing such networks is an inherit problem raised in a study by Cheng, Yang and Sheu (2016, p.83) reinforcing the notion that a firm’s cognitive attention is a limited resource, working on too many ideas simultaneously may result in insufficient attention being paid to each individual idea. This problem has been previously identified by Laursen and Salter (2006); Laursen, 2012; de Leeuw, et al; (2014) and Clausen (2014). Ultimately the firm’s technology seeks to improve the curing times of carbon fibre and composite materials. Within the industry a curing time of one minute or less is the benchmark figure that needs to be cracked to propel the firm’s technology to wider commercial industry applications. It is unclear how this will be achieved; other manufacturers are having said to achieve this with different curing technology.

2. Facilitating variation

The firm recently transformed several technological processes into combined ‘fibre to part’ – or as referred to by the company – as a ‘build to print’ manufacturing process. Previously, the company had only dealt with developing the technology for curing the part and that was when the company

was looking to license or sell the process technology to other people. The company recently made the decision to move towards making parts themselves; adopting a built-to-print finish process. As the firm's executive manager explained, this was achieved by developing in-house manufacturing operations using their technology that combines the *"curing bit, cutting fibre, pre-forming it, curing it, trimming it, painting the part and assembling processes creates a complete fibre to part or fibre-to-finish process it, so you're doing the whole process."* The focus of recent times has been to maximise the cure technology to get volume. The firm's new strategy was to build the whole system around their technology. The firm provides for variation in that it uses the firm's intellectual property and 'know how' (DU&I) to meet the specific needs of its customer's product requirements... *"it's different for every customer because every customer's part is a different geometry, it's different volume, is it a large flat part, is it a short fat part, is it a deep drawn part?"* These customer design parameters require a unique design solution developed each time by adopting a DU&I learning process – the firm's executive manager explained.

3. Sharing knowledge and superior practices across the organisation; and Managing adaptive tension

The curing time of one minute or less is the 'golden' benchmark industry standard that firms seek to crack to propel a firm's technology to wider commercial industry applications. It is unclear how the firm will achieve improved curing times despite other manufacturers having achieved this with different curing technologies. In 2016 research undertaken by Deakin University supported a rival firm to develop suitable processing techniques for a resin material used by a European OEM that claimed to achieve this industry standard. For this research the University was awarded joint winners of the 2016 JEC Asia Innovation award in the automotive category. It is unclear how this University work and expertise is not translated to this firm's own technology; however, this is probably attributed to the technological complexity of different curing technologies, patents, and trade secrets. Despite this tension the firm continues to collaborate with the University to advance its technological development and has several joint projects being carried out with PhD students.

4.6.3 Antecedents of Transformation

Like assimilation transformation processes involves internal factors to a firm's intra-organisational learning activities to include:

- facilitating variation;
- managing internal selection regimes;
- sharing knowledge and superior practices across the organisation;
- reflecting, updating, and replicating; and
- managing adaptive tension.

Transformation is the third phase attributed to the start of a firm's Realised AC. This stage and associated learning activities each firm parallel much of the later phases of the NPD process to achieve commercial success. In this phase, the role of financial funds is important to get the technology to this point. The venture capital to commercialise the technology has been raised through several methods: principally self-funded from revenue derived from other parts of the firm's

operations; secured loans from private financial providers and investors; and all the firms have been the recipients of government funds – some in the order of millions of dollars. The top AC activities across all the firms include ‘facilitating transference and novel associations concerning the knowledge’ (AC 3.3); ‘constructive combination and re-combination of knowledge’ (AC 3.6) and ‘adding new knowledge to the acquired knowledge’ (AC 3.5) – the overall trend patterns do vary considerable within each firm as discussed further below.

Table 27: Frequency Ranking of Coding Results - AC 3 Transformation

AC 3 Transform Sub-code	Firm 1	Firm 2	Firm 3	Firm 4	Total
AC 3.3 Facilitating transference and novel associations concerning the knowledge	3 rd	1 st	4 th	4 th	54 - 1 st
AC 3.6 Constructive combination and re-combination of knowledge	2 nd	2 nd	2 nd	2 nd	54 - 1 st (equal)
AC 3.5 Adding new knowledge to the acquired knowledge	1 st	3 rd	2 nd	1 st	45 - 3 rd
AC 3.1 Creation of new knowledge based on the acquired knowledge	4 th	4 th	1 st	3 rd	32 - 4 th
AC 3.2 Reconstructing acquired knowledge	5 th	5 th	6 th	6 th	17
AC 3.4 Discursive interpretation of knowledge	6 th	6 th	6 th	5 th	15
AC 3 Total	40	116	11	50	217

Transformation reflects a firm’s capacity to develop and refine the routines facilitating the combining of the old and new knowledge. There are times when a firm needs to specifically make changes to its operations to assimilate new knowledge. This process of assimilation and transformation may depend on the firm’s receptivity, as well as the extent the firm can make sense of the new knowledge with reference to changing its internal operational procedures. This phase sees the firms move into early industrialisation stage of its technology for production for commercial applications. The technology is scaled to where it can demonstrate the production of output that could suit the needs of commercial operations to meet specific quality outcomes, technical standards and volumes of potential parts. During this stage added new knowledge is combined to an existing patented/licenced technology.

The added new knowledge is a result of industrial research refinement, often involving several parties, in a continual evolution of the technology’s potential. This largely sees the firms conducting significant testing and validation of the new processes and involves an intuitive and iterative process of trial and error. Depending of the firm’s technology base this may take several months to several years, and the greater certainty of realising the potential is provided by industry standards that are set by the regulatory authority or an OEM. For example, in the case of firm one, this is set by the CE standards regulated by European Union for their markets. In the case of the second firm, the realisation of its technology is also dominated by its users’ satisfaction, and it workshops with its market to ensure its technology and new product innovations are adopted into its supply chain. In

the case of firm three and four, the benchmarks are set by OEMs and other technological partners in its global supply chain.

Firm 1

1. Sharing knowledge and superior practices across the organisation; and Reflecting, updating, and replicating

The firm's top three activities are (i) 'adding new knowledge to the acquired knowledge' (AC 3.5); (ii) 'constructive combination and re-combination of knowledge' (AC 3.6); and (iii) 'facilitating transference and novel associations concerning the knowledge' (AC 3.3). The first two activities reflecting a higher average proportion than the overall averages for all the firms and these activities dominate the firm's responses. The firm benefits from a first / early entry advantage. It has developed its innovation capabilities around its marketing position as the first firm to produce the novel concept of protective denim garments (jeans) to motor cyclists from 1997. It involves the adaptation of established fibre technology with incremental R&D advances with its use through university laboratory testing, textile design and knitting manufacturing DU&I 'know-what' to deal with the strong nature of the adopted fibre technology.

2. Managing adaptive tension

Many rival firms have since developed similar products. The firm has been able to remain competitive over its rivals through its early first mover advantage; adoption of highest personal protection standards; and its continual pursuit of exploring incremental product innovations with its unique manufacturing process, patented knowledge and R&D investment with the University. The firm has remained competitive on quality and brand reputation. It has provided different market segments with a variety of designs and products in different global locations. Its product is produced and sold in the US under a different brand because of an early US partnership using its brand name dissolved. The US partner kept the firm's brand name after the two parties separated; leaving the firm to re-establish the technology. Its IP was adequately protected ensure it could forge the product under the new brand name to the large US market.

Firm 2

1. Sharing knowledge and superior practices across the organisation; and Reflecting, updating, and replicating

The top learning activities across the firm include (i) 'facilitating transference and novel associations concerning the knowledge' (AC 3.3); (ii) 'constructive combination and re-combination of knowledge' (AC 3.6); and (iii) 'adding new knowledge to the acquired knowledge' (AC 3.5). The first of these two activities dominated the firm's responses. The figure for AC 3.3 stands out as the dominant activity (34.7 percent), well above the overall average for all firms. The reasons for this derive from the firm's international connections with advanced R&D programs connected to both a renowned North American university and established links to a Swiss University and Swiss national research institute. The local Australian business operations benefits by having internal staff with technology management capabilities. The Australian operations have benefits from sophisticated international

networks that includes a vast range of prior industry knowledge with an existing suite of adopted commercially successful products developed other technology platforms. This background with an ability to ‘construct combination and re-combinations of knowledge’ that represents the formalised research arrangements made between the firm and the University in 2015 and its collaboration with the co-creators of the SPF synthesising machine (Cytomatrix Pty Ltd and Austeng).

Firm 3

1. Sharing knowledge and superior practices across the organisation; and Reflecting, updating, and replicating

The top three activities for firm three are (i) ‘creation of new knowledge based on the acquired knowledge (AC 3.1); (ii) ‘adding new knowledge to the acquired knowledge’ (AC 3.5); and (iii) ‘constructive combination and re-combination of knowledge’ (AC 3.6). AC 3.1 accounted for over 50 percent of the firm’s responses and the remaining two sitting just below the overall average for the total firms. The reason for such a high response rate could be that, whilst the existing firm’s IP technology for its automotive carbon fibre wheel forms the core of the technological capacity of the business, the firm requires ongoing knowledge and technological exploration for other wheel applications in its targeted industry sectors. As such the continual investment to exploring new knowledge continues to develop new IP for additional uses of the carbon fibre wheel. As seen by the firm’s financial commitment to the ARC Transformation Hub research project to 2020.³⁶

In terms of the projects coming out of the ARC funding and your interest, is that fairly clear in the proposal that was approved, you put money in, are you clear on what you want to get out of it or was it evolutions in concept? Can you explain a bit about that?

So when Deakin were applying for the Fibre Hub we were certainly on board with wanting to have that happen here and we definitely supported that application with a range of broad projects that we could see were relevant at the time for the industry and for the people here, Quickstep and us and whoever else was involved.

In your own vested interests obviously?

Correct. So we certainly saw that as valuable. Then when the hub was awarded that was all good and then we had to obviously put in some cash to get things started. It was a little difficult at that point in time because we were actually needing to put money into this Fibre Hub without having to find projects or outcomes.

So from a commercial perspective for our company, we’re being asked to commit to \$500,000 of funding over four years or whatever that works out to be without knowing what we’re going to get from it, without having projects to find.

I believe there will be proposals for projects developed which will specify –
After that point, yes.

And that’s where you can get that clarity potentially?

Absolutely. So that happens later, but from an order of things occurring.

2. Facilitating variation

The firm has diversification plans to adapt the carbon fibre wheel technology to applications across sectors such as aerospace, defence, public transport and haulage, which represent areas of great potential, where the light-weighting benefits of CR’s technology would be highly advantageous.

³⁶ <http://futurefibreshub.com.au/>.

“We’re close to signing an agreement with a big offshore partner in the aerospace sector, where this technology has an even more logical place than in the automotive industry,” says Dingle. “It’s an absolute no-brainer, taking 40 percent-50 percent of the weight out of aircraft wheels: there are huge benefits. That’s the next horizon of our strategy really, but we had to get the automotive part bedded down properly before the distractions of trying to diversify.” One thing that’s not on the agenda is any move away from the wheel itself. “There are thousands of things we could diversify into, and many of the things we’ve developed to make these wheels are applicable to other products. But with 60m-70m cars built every year, and then trucking and aircraft, it’s a long time before we start running into demand shortages for this sort of technology” says Dingle.³⁷

The firm has a unique well-developed patented core technology that forms the knowledge foundation of its current product range. The ongoing transformation of its technology involves particularly where it is looking to expand its manufacturing processes for carbon fibre wheels into other transportation markets such as aerospace. It’s interesting to compare the firm three with four, these two groups deal with use of carbon fibre composite materials and developing that into products. Co-founding firm owner and inventor provides an explanation to why the firm restricts its technology development to wheels – as they explain...

“That’s where all our IP is, that’s what we’re focused on, that’s where we see the most benefit for light-weighting in industry, unsprung, rotating mass. There’ll definitely be new IP for different applications. We don’t really worry too much about whether we can transfer our current IP to a different application. We’re more focused on the different application, the market, what we need to develop to access it. So we’re not saying this is our IP today and we’re going to see what we can do with it, we’re just very keen to develop whatever IP we need in composite wheels to develop those new applications.

For example, an aircraft wheel requires different material properties to an automotive vehicle. So we know that our processes for making an automotive wheel will have to change if we were making an aircraft wheel. So we’re off actually working on how to process the material for an aircraft wheel today, so we’re qualifying that material, learning about the processes that we’ll need. The structure and the design of an aircraft wheel’s very different, the loads are very different to an automotive wheel. So we’re doing that from a first principles project.”

Firm 4

1. Facilitating variation; and Reflecting, updating, and replicating

The top responses for the fourth firm include (i) ‘adding new knowledge to the acquired knowledge’ (AC 3.5); (ii) ‘constructive combination and re-combination of knowledge’ (AC 3.6); and (iii) ‘creation of new knowledge based on the acquired knowledge’ (AC 3.1); all three responses are above the averages for the total firms. Firm four has the longest collaborative history with the University. The University has contributed to several research projects to assist the development of the firm’s technology and knowledge base; particularly in the areas of resin development and material processing of carbon fibre and other compatible light weight material composites. The firm continues to exploit new technology for business development. It announced a composite seating development

³⁷ <http://www.amtil.com.au/News/AMTIL/Carbon-Revolution-per-centE2-per-cent80-per-cent93Wheels-of-fortune#.WqXZq-hubIU>

project with Futuris Automotive, which focuses on utilising latest manufacturing processes to deliver annual volumes more than 20,000 units/annum. Other intermediate parts development projects currently underway at the firm's New Technology division include a composite front fender for a European vehicle manufacturer and composite body panels. Quickstep will also be working with Deakin University on an Advanced Manufacturing Growth Centre (AMGC) project, which will be focusing on automated manufacturing techniques that can reduce the cost of creating complex shaped components that have traditionally been made using manual 'lay-up' techniques. This work was supported for \$0.25 million grant was awarded by the AMCG to support full scale tooling for composite automotive fenders with the firm and Deakin University. Initial discussions with European car makers have shown significant interest in the project, leading to a forecast that the market for such bumpers could be worth \$25 million annually.

The firm still pursues the exploitation of its older traditional curing technology practices with the Defence sector; it simultaneously has envisaged manufacturing the first aerospace parts using the QS Process, for example: the spars for the vertical tails of the F-35 Lightning II Joint Strike Fighter. The firm expects that, depending upon their performance in testing, the spars for the vertical tails will either be produced or certified separately, or concurrently with identical parts produced using traditional autoclave techniques. Although having the traditional approach as a benchmark will certainly accelerate the process, the firm did not expect qualification of the QS Process to produce these spars to occur before the first half of 2015. *"Once the QS Process is qualified by one OEM in one high-end application, the path to qualification for other parts in other applications by all OEMs will be greatly accelerated"* the former CEO of the firm said.³⁸ Unfortunately, these expectations have yet to be realised by the company as discussed in the case study.

4.6.4 Antecedents of Exploitation

Pursuant to literature on AC antecedents (Volberda et al., 2010), both managerial conditions and inter-organisational learning are factors to exploiting new knowledge from external sources. In terms of inter-organisational factors Lewin, et al (2011) identified the following external AC routines:

- Identifying and recognising value of externally generated knowledge
- Learning from and with partners, suppliers, customers, competitors, and consultants
- Transferring knowledge back to the organisation

Table 28: Frequency Ranking of Coding Results - AC 4 Exploit

AC 4 Exploit Code	Firm 1	Firm 2	Firm 3	Firm 4	Total Firms
AC 4.1 Applying knowledge to commercial purposes	1 st	1 st	6 th	1 st	72 - 1 st
AC 4.3 Converting innovative ideas into commercial applications	3 rd	2 nd	2 nd	2 nd	61 - 2 nd
AC 4.5 Engaging product or service innovations	2 nd	3 rd	2 nd	3 rd	52 - 3 rd

³⁸ [https://www.amscot.com.au/Download/Download?file=SOSL_-_May_2013_-_Quickstep_Holdings_Ltd_\(QHL\)_1.pdf](https://www.amscot.com.au/Download/Download?file=SOSL_-_May_2013_-_Quickstep_Holdings_Ltd_(QHL)_1.pdf)
published 14/05/2013

AC 4.6 Commercial use of knowledge	4 th	5 th	1 st	4 th	43 – 4 th
AC 4.4 Using generated and disseminated knowledge in market activities	6 th	4 th	4 th	5 th	31
AC 4.2 Launching innovations to the market	5 th	6 th	5 th	6 th	23
AC 4 Total	78	121	21	62	282

Firm 1

1. Identifying external knowledge and routines for learning from and with external organisations;

The top responses for this firm include (i) 'applying knowledge to commercial purposes' (AC4.1); (ii) 'engaging product or service innovations' (ACC4.5); and (iii) 'converting innovative ideas into commercial applications' (AC 4.3). The results are consistent with the overall average for all firms, with the first two above the all firm average figure. The figure for engaging product or service innovations accounts for almost 22 percent of responses and this reflects the firm's lack of internal R&D staff and reliance on collaborative research partnering with the University for advancing its product innovations. The firm's early product development has relied upon access to the supply and application of highly advanced fibre technology made available from a multi-national supplier. Further exploitation opportunities developed from the initial release of its CE level 1 products in 2010 lead to a range of products at the CE level 2 in 2013. The continued exploitation of the firms constructed knowledge has been combined in a variety of different products for the market. Most recently, the firm added further product varieties to the market place in 2018 with expanded clothing protection range; this range extends the durability of fabrics used to expand upon its patented technologies and further collaborations with the University.

Firm 2

1. Identifying external knowledge and routines for learning from and with external organisations;

The top responses include for this firm include (i) 'applying knowledge to commercial purposes' (AC 4.1); (ii) 'converting innovative ideas into commercial applications' (AC 4.3); and (iii) 'engaging product or service innovations' (AC 4.5). Of the top frequent responses; AC 4.1 and AC 4.3 are above the average scores for the total firms. This stands out due to the strong commercial focus of the firm's business strategy and internal operations, coming off a long pipeline of innovative textile technologies on the back of the success of the firm's international parent company in Switzerland. After the initial small laboratory scale machine was designed by the University in 2009, it has been scaled up further with two additional larger machines in 2013 and 2014. In November 2014 the firm entered a Joint Venture Agreement with Cytomatrix Pty Ltd to develop the short polymer fibre technology into industrial scale capabilities to manufacture SPFs and a \$2 million joint research program with Deakin to commercialise the technology originally developed by the University.

The firm has benefited from working with IFM at the University which can be attributed to its desire to improve international research visibility and impact and connecting researchers with SMEs. The University has a program for engaging with Geelong business to plans to and are extend the program to other regional hubs in Victoria. A major emphasis of the University research plan is to forge strong collaborations and partnerships while maintaining very high ambitions for exploratory and discovery research. IFM plays an important role in the University's research plan *'to deliver and translate high quality research and research training outcomes that are relevant and meaningful to improving the future of our communities'*. The IFM team assists HQ Australia to develop world-first short fibre materials that offer enormous potential in textile applications.

Its first product, HQ Real Silk, reproduces the luxurious tactile properties of silk and the short fibre material is manufactured in the Geelong Future Economy Precinct at Waurn Ponds. This export product is used in the global textile market, including apparel and home textiles, such as bedding. *"So that's happening now. We're implementing a project now which scales it up to the first level where we can really start to do that and that's where the connection back to the parent company in Switzerland helps, particularly in the textile market channel. So from the point of view of HQ Australia, HQ Switzerland is the client because the materials we make here are used in products that are sold through that company into the textile world."* So, the next step is yourselves, Switzerland and then to the textile industry itself? *"That's right..."* To produce a fabric textile itself? *"Yeah."* *"The nature of the business is very B2B oriented, so the types of materials we sell we don't sell to the consumer, they're a very specialised functional ingredient."* This collaboration has culminated in several milestones including an early market commercial application of the technology that created an innovative product called HQ Silk in 2016. A second commercial product innovation from this technology platform was released in May 2018 to the firm's markets. This represents a continuous example of the collaboration between the firm and the university under its R&D partnership.³⁹

Firm 3

1. Identifying external knowledge and routines for learning from and with external organisations;

The top response for this firm appears the least consistent with the average firm totals for exploitation phases. It records 'commercial use of knowledge being the highest most frequent response' AC 4.6, which is substantially higher than the other firms score for this sub-dimension and several percentage points above the average response for all firms. The remaining two dimensions of 'converting innovative ideas into commercial applications (AC 4.3) and 'engaging product or service innovations' (AC 4.5) are consistent with the pattern for all firms, sitting at or close to the averages for both. The firm's ongoing commercial application for OEM markets of its technology requires the conversion of new knowledge and technological explorations. It is heavily reliant on its internal R&D team to work with its various partners, including its equity partners (Ronal Group) and the University, to develop

³⁹ <http://www.deakin.edu.au/about-deakin/media-releases/articles/no-fuzz-new-deakin-treatment-does-away-with-fabric-pilling?cn=ZmxleGlibGVfcmVjcw%3D%3D&refsrc=email>

commercial inroads into other industries, such the aviation / aerospace sector, which could benefit from light weight carbon fibre single wheel technology. The firm's CEO Jake Dingle said his team was working with Deakin's neighbouring Carbon Nexus facility to improve wheel design and reduce manufacturing costs. He said improved affordability would drive the expansion of his business, not just in the automotive industry, but also in aerospace and industrial sectors. *"There's a lot of technology to happen, and we've got a great team to do it. It's a very logical technology to take into that (aero) market; the value of weight-saving for aircraft is even more significant for land-based vehicles."* he said.⁴⁰ A recent research collaboration \$13M funding deal approved in June 2018 has given the firm the firms the necessary ongoing support to further commercialise its technology and exploration into new market sectors. This deal is delivered in partnership with the Australian Government's NISA agenda and the Innovative Manufacturing – CRC.

Firm 4

1. Identifying external knowledge and routines for learning from and with external organisations;

This firm's results are consistent with the overall average pattern for all firms, with notably addition of AC 4.6 'commercial use of knowledge' as the fourth most frequent result and all are well above the average score for all firms. AC 4.1 'applying knowledge to commercial purposes'; AC 4.3 'converting innovative ideas into commercial applications' and AC 4.5 'engaging product or service innovations' are the firm's top most frequent interview responses. Throughout 2017 and into the immediate future, the firm will continue to advance the industrialisation of their Qure and RST technologies for use in the aerospace, defence, marine, automotive and other transportation sectors. There are several restrictions to the firm's exploitation opportunities with one its major targeted sectors in the form of International Traffic in Arms Regulations (ITAR) that pertain to defence security and intellectual protections required by the US defence industry.

2. Learning from and with partners, suppliers, customers, competitors, and consultants and Transferring knowledge back to the organisation

The firm works with the University on material processing – such as resin developing for curing purposes within the new technology developed by the firm. It requires continuing exploration of knowledge through process development projects with potential customers, with the goal to lower the curing timeframes while demonstrating its technology can reach a desired structural quality and integrity at the production volumes required by many global OEMs. The technology has been steadily progressing through the technical ratings maintained by the OEMs. It is unclear how an expertise developed by the University for a rival firm is not able to be translated to this firm's own technology and more widely, other than for trade secrecy and IP protection measures. It is could be attributed to the technological complexity of different curing technologies. The firm continues to collaborate with the University to advance its technological development and has several joint projects being carried

⁴⁰ <https://www.transforminggeelong.com.au/latest-news/95-carbon-revolution-s-25-million-wheel-deal-with-ford-sees-staff-double-published-date>

out with PhD students to achieve greater efficiencies in faster curing times of advance light weight carbon fibre composite materials.

The firm's business model originally was to generate multiple revenue streams from equipment and licence sales to major aerospace, automotive and marine manufacturers; joint venture arrangements and co-branding and co-marketing agreements with leading composites manufacturers (OEM's, Tier One suppliers and alliance partners); and contract and in-house manufacturing operations and sales utilising its patented technologies and processes. The firm has ceased licensing and selling its technology as a business strategy. It is unclear how or if the firm can work with its previous customers on the use of the technology and therefore a possible learning channel is potentially squandered. The firm's specific technological focus suffers from longer NPD project timeframes. There are limited markets for its technological application, and commercial approval and acceptance to its technology by the market relies on experimental process development and feasibility projects with long periods of 'testing and trials' to seek approval as OEM to potential customers, which are predominantly overseas.

As the firm's application of its technology has many potential applications for the aerospace and automotive industry, many of the larger manufacturers are fairly risk averse and set rigorous quality testing before the firm is registered as a potential supplier of manufactured parts and technology to an OEM. This innovation activity is a high-risk and costly deployment of internal R&D staff, resources, time and expense. It is a strategy that is not guaranteed to pay off, certainly not in the short term. Other elements of the firm's technology have been subject to several similar PhD research projects, to the extent that the level of new knowledge has been limited and diffused over time and partially lost. This is partly attributed to change of staff at the company and the university, with loss of 'organisational memory' and lack of continuity of knowledge creation due turnover of production and R&D staff in last few years. Several of the initial product development exercises with global OEMs in the automotive sector with its technology looked promising but none have developed to full commercial contracts. Similarly, the work with OEMs in the aerospace industry is hindered by slow and rigorous industry requirements to fully achieve acceptance of the firm's technology with the design and manufacture of domestic passenger aircraft. The technology has for been steadily progressing through the technical ratings maintained by the OEMs.

5 CHAPTER FIVE: CROSS FIRMS DATA ANALYSIS

This chapter will discuss the analysis and findings of the case study data. The use of 'cross-firm' analysis provides the most powerful means to draw out patterns and themes from the data. Using some basic quantifiable measures – such as frequency of responses, total response averages and percentages across the coded data – reveals strong similar patterns across the firms. It also reveals unique 'nuances' within each firm where the data may indicate a deviation from the main patterns/themes identified. From a firm's perspective – depending on the business needs – collaboration with the University on knowledge creation projects will vary in terms of the following considerations:

- the level and nature of a firm's AC developmental pathway;
- timeframes/scale of the NPD process;
- the level of novelty required, such as the need for a solution to an immediate business problem – versus longer term new product exploration and technology development;
- ability to fund research into product innovations;
- research partner to develop the firm's product range to meet new customer/consumer market demands; and
- developing responses to emerging new science and technology knowledge.

5.1 Zahra and George's (2002) AC Learning Processes

Adopting Zahra and George's (2002) AC model for this study allowed for strong patterns to be identified between each specific AC learning process and their sub-dimensions as outlined in the coding structure applied in the study. What emerged included several AC dimensions having a stronger resonance to the firms over others. The interview responses tended not to provide an overt or explicit narrative of a learning organisation that reflected the formalised adopted AC code structure developed by Gebauer, et al., (2012). The ability for firms to articulate how they deploy new knowledge is revealed by an in-depth analysis of the interviews supplemented with use of secondary data sources as relied upon in the case study. Greater detail is obtained about the activities each firm performs through the induction analysis of the coded interview transcripts. This tends to be discussed at an operational level rather than the strategic learning processes deployed to reflect the 'dynamic capability' perspective. For example, when prompted some firms were able indicate some specific internal procedures deployed, such as established project management and relevant sector-specific applications of ISO 9001 quality standard practices.

The results of this thesis can be broadly compared and discussed for generalisation purposes to the study by Gebauer, et al., (2012) along with AC models either developed by Lane et al. (2006); Todorova and Durisin (2007) or reviewed and extended by Patterson and Ambrosini (2015) and Aribi and Dupouët (2016). Gebauer, et al., (2012) identified the relative importance of AC by using Zahra and George's (2002) efficiency ratio between each of the four AC learning processes. The Gebauer, et al., (2012) study of two large firms examined how firms managed the accumulation of external knowledge to adapt their combinative capabilities (*systematisation, coordination, and socialisation of*

knowledge) as shown in table 29. The coding structure used in this study's data analysis reflected Gebauer, et al., (2012) attributes that they developed in their study of two firms across the AC process, along with the additional use of questions to determine the effect of two variables:

- (i) business '*combinative capabilities*' (Kogut & Zander, 1992) that mediates the relationship between AC learning processes and innovation outcomes; and
- (ii) business '*network position and innovation strategy model*' moderated the historical evolution of AC learning processes and combination capabilities (Gebauer, et al., 2012, p.59).

Table 29: Combinative capabilities

Combinative Capabilities
1. Coordination capabilities
<ul style="list-style-type: none"> • Degree of job rotation applied (number of job rotations, length and breadth of job rotation, formalisation of job rotation) • Degree of cross-functional interfaces (e.g., intensity of communication across different functions, knowledge exchange among different teams and functions, demands for periodical cross-functional meetings) • Degree of participation in decision-making processes (vertically-centralised versus horizontally-decentralised decision making, empowerment of middle and lower management, number of managers participating in decision-making processes, emphasis on cross-functional support)
2. Systematisation capabilities
<ul style="list-style-type: none"> • Degree of formalising knowledge (e.g., predefined templates, procedures, and methods) • Degree of 'routinisation' for systemising knowledge (e.g. flexibility on templates, procedures, and methods)
3. Socialisation capabilities
<ul style="list-style-type: none"> • Intensity of social relations • Density of social linkages • Shared social experience such as education, gender, and role understanding • Gender diversity of participants (ratio male and female executives) • Diversity of role understanding and attitudes among the participants
Network Position & Strategy
1. Strategic behaviour
<ul style="list-style-type: none"> • Emphasising pioneering advantages • Importance of market timing • Strategic ambitions on ensuring time to market • Importance of benefiting from first-mover advantages
2. Network position
<ul style="list-style-type: none"> • Centrality of network position • Prioritising knowledge exchanges in the network • Channelling knowledge created in the network • Listening to and discussing with other network partners • Collaborating with network partners • Balance of knowledge contribution among network partners
3. Strategic innovation
<ul style="list-style-type: none"> • Degree of changes in the business model (e.g., value proposition, revenue and profit mechanisms, value chain) • Newness of market spaces (e.g., number of potential competitors, closeness to other markets) • Customer value (e.g., perceived customer value, degree of newly addressed customer needs)

Colombo, Dell'Era, and Frattini (2015) defines the capabilities firms need to benefit from collaboration with different innovation intermediaries and partners, depends on its level of AC. This is conceived as a set of organisational capabilities concerning the acquisition and assimilation of external knowledge and its transformation into new products, services and processes (Kogut and Zander, 1992; Eisenhardt and Martin, 2000). This set of capabilities relies on those combinative capabilities (systematisation, coordination, and socialisation of knowledge) as labelled by Kogut and Zander (1992).

Coordination capabilities are those that '*enhance knowledge absorption through relations between members of a group*' (Van den Bosch et al., 1999, p. 556). These capabilities refer to specific organisational mechanisms, such as cross-functional interfaces, participation in decision making and job rotation, which favour knowledge sharing and absorption within an organisation (Henderson and Cockburn, 1994; Van den Bosch et al., 1999).

System capabilities allow firms to 'program behaviours in advance of their execution and provide a memory for handling routine situations' (Jansen, et al., 2005, p. 1002). They enable firms to develop organisational routines that lower the effort spent on decision making by providing an efficient structure for collective action (Cohen and Bacdayan, 1994). System capabilities also improve a firm's ability to efficiently tackle unexpected situations that might surface during collaboration with innovation intermediaries, thus streamlining the assimilation and use of external knowledge.

Finally, **socialisation capabilities** 'create broad, tacitly understood rules for appropriate action' (Jansen, et al., 2005, p.1003) and contribute to establish shared values and dominant codes of communications. This benefit favours communication among people with different educational backgrounds and professional experience and therefore eases the interaction with providers of knowledge coming from different educational and geographical backgrounds (Fisher, 1986; Chao et al.,1994).

The importance of looking at the capabilities firms deploy to extract the maximum value from collaboration with innovation intermediaries derives from the tacit nature of the knowledge they exchange with their external partners, which requires particular managerial attention to be properly transferred and assimilated (Bianchi, et al., 2011). Moreover, the literature on organisational integration in NPD processes (e.g., Souder, et al., 1998; Millson and Wilemon, 2002) points to the importance of cooperation and communication between different functions (e.g. R&D, marketing and operations) and with external organisations participating in the NPD process for the successful completion of the innovation process. Capabilities that ease the interactive nature of this process are therefore of particular importance during collaboration with innovation intermediaries. Colombo, et al., (2015) analysis suggest that each of the capabilities presented above becomes especially critical when a firm collaborates with a particular category of innovation intermediaries (Colombo, et al., 2015, pp.130-131).

5.1.1 The role of AC Learning Processes

Gebauer, et al., (2012) indicated firms place a high significance on the acquisition learning processes (31 percent for firm 'Alpha' and 34 percent for firm 'Beta'), and slightly higher on the exploitative learning processes (46 percent for Alpha and 38 percent for Beta) – which follows this study's findings but are significantly different in the relative importance of assimilative and transformative learning processes. This case study's data shows that acquisition learning processes (AC 1 - 37 percent) following by exploitation (AC 4 - 29 percent) are clearly the dominant learning behaviours of these firms, as shown in table 30, followed by transformation (AC 3 - 22 percent) and assimilation (AC 2 - 12 percent) as the least identifiable phase as derived from the interview transcript data.

Table 30: Identified dominant AC Learning Processes

AC	Total	(%)
AC 1 Acquire	354	37
AC 4 Exploit	282	29
AC 3 Transform	217	22
AC 2 Assimilate	112	12
Total	965	100

The data analysis reveals Realised AC to be a slightly more dominant stage (51 percent) when compared to Potential AC (49 percent) – shown in table 31; this is not considered a significant difference. This reflects the overall dichotomy of the concept and more broadly the organisational ambidexterity conundrum. This discussion raises several considerations about how firms transition

from Potential to Realised AC across the four learning dimensions and introduces the notion of a firm's efficiency ratio identified by Zahra and George (2002). To take this analysis further, the coded AC learning processes resonant the greatest with the first two firms recording 54 percent and 57 percent for Realised AC respectively in comparison to its Potential AC of 46 percent and 43 percent respectively. This pattern is reversed for the third and fourth firms – with Potential AC responding higher for these firms (64 percent and 54 percent), and less for Realised AC (36 percent and 46 percent).

Table 31: Firms achieve Organisational Ambidexterity

AC Stages	Firm 1 (%)	Firm 2 (%)	Firm 3 (%)	Firm 4 (%)	Total (%)
Potential AC	46	43	64	54	49
Realised AC	54	57	36	46	51

The Gebauer, et al. (2012) study is a more powerful piece of empirical research that determines, not only the role of AC learning process to strategic innovation, but also the effect of these other independent variables [*combinative capabilities' network position and innovation strategy model*] to the sequence and effectiveness of the different learning process. Nevertheless, despite this consideration, it is useful for discussion purely for general comparison purposes. The relative importance of learning processes differed substantially between these two firms labelled as 'Alpha' and 'Beta'. These two firms were significantly different in the relative importance of assimilative and transformative learning processes. For the firm Alpha, the transformative learning process is of limited importance (2 percent), whilst assimilative learning dominates the linkage between exploratory and exploitative learning (21 percent). For the firm Beta, the transformative learning dominates (24 percent) and assimilative learning is of limited importance (4 percent). Alpha fully transforms the potential knowledge stock into commercial purposes as such achieves its Realised AC, and a higher efficiency ratio.

In this study the only substantial observable difference to the frequency and order of the four AC learning process across each firm is for firm one and three. Exploitation process are greater (36 percent) than acquisition (32 percent) for the first firm; and transformation is slightly lower (12 percent) than for assimilation (15 percent) for the third firm, as shown in table 32. Once again, the assimilation learning process appears the weakest learning domain for all the firms. The results of this case study are similar to the firms in the study of Gebauer, et al., (2012). The first and second firms reflect the experiences of the firm 'Alpha', with a higher efficiency ratio where firms tend to expend more of their capabilities with transforming and exploiting – and are labelled as 'Realised AC dominant' in this study; while third and fourth firms reflect the results of the firm 'Beta', with a lower efficiency ratio where firms tend to expend less of their capabilities with transformation and exploiting – and are labelled 'Potential AC dominant' in this study.

Table 32: Dominant AC Learning Process across all Firms

AC Stages	Firm 1 (%)	Firm 2 (%)	Firm 3 (%)	Firm 4 (%)	Total (%)
AC 1 Acquire	32	33	49	42	37
AC 2 Assimilate	14	10	15	12	12
Potential AC	46	43	64	54	49
AC 3 Transform	18	28	12	21	22
AC 4 Exploit	36	29	24	25	29
Realised AC	54	57	36	46	51

The variance between the first two firms and the last two SMEs could be attributed to the fact that the larger two SMEs explore greater radical innovations that require more time in the potential ('gestation') phases before being realised for exploitation. This seems like a simplistic explanation, but it resonates with the literature and the more detailed analysis of the interviews. As discussed above, Realised AC appears to be a marginally more dominant than the former. The intensity of efforts (or a 'firm's efficiency' ratio) based on the work by Zahra and George (2002) and adopted by Gebauer et al. (2012) does vary between each learning phase of the AC concept for each of the firm's innovation journeys as they collaborate with the University.

We term the ratio of RACAP (realised) to PACAP (potential) as the efficiency factor (7q). The efficiency factor suggests that firms vary in their ability to create value from their knowledge base because of variations in their capabilities to transform and exploit knowledge. In firms with a high efficiency factor, RACAP approaches PACAP. Given that profits are created primarily through RACAP (Grant, 1996), firms that achieve or maintain a high efficiency factor are positioned to increase their performance (Zahra and George, 2002, p.191).

Gebauer, et al., (2012) also shed light on the discussion on the sequence between the acquisition, assimilation, transformation, and exploitation of knowledge (Jansen, et al., 2005; Lane, et al., 2006; Todorova and Durisin, 2007; Zahra and George, 2002). The discrepancy between the firms' levels of assimilation and transformative processes varies for a variety of reasons and circumstances. Gebauer, et al. (2012, p.71) go on to suggest that transformation learning processes are essential for firms to convert potential knowledge stocks into commercial purposes. This requires more than just a high efficiency factor, as a few strategic selected actions can enable firms still to achieve strategic innovations. As they found in their study the efficiency factor seems to be a limited predictor of strategic innovations. "Our findings are more in line with Winter's (2000) aspiration-level framework. Aspirations should not merely aim at increased efficiency factors; instead, approximate aspirations should be set for exploratory, transformative, and exploitative learning processes." Gebauer, et al., (2012) findings support the feedback process perspective on AC (Lane, et al., 2006; Todorova and Durisin, 2007), and depart from the linear approach to AC (Jansen, et al., 2005; Zahra and George, 2002).

In combination with the former sequence of learning processes, aspirations for the transformative learning process play a key role in strategic innovation. Strategic innovation benefits from aspirations that transforming knowledge is interrelated with changing existing combinative capabilities. Departing from existing configurations in combinative capabilities suggests that AC also involves the

unlearning of capabilities. Adding to Todorova and Durisin's (2007, p. 777) argument that "...firms often fail to identify and absorb valuable new external knowledge, because they are hampered by their embedded knowledge base, rigid capabilities, and path dependent managerial cognition...", rigidities exist specifically in how knowledge is systematised, coordinated, and socialised. Their study (Gebauer, et al., 2012, p.71) highlights the significance that firms 're-configure' their combinative capabilities. For example, exploratory and transformative learning processes benefited from:

- decreased formalisation and more interdisciplinary routines for knowledge systematisation, cross-functional interfaces,
- job rotations,
- 'umbrella strategy' for knowledge coordination, as well as increased cognitive diversity; and
- denser social linkages.

5.2 Overview of Individual Firms Analysis

The firms in this case study are the weakest with assimilation activities and that could suggest several matters for consideration. Firstly, in terms of the AC literature, the finding could indicate for some 'highly innovative' firms' assimilation learning processes are less important for the firm's innovation performance outcomes. Where new knowledge is closer to a firm's prior knowledge it is absorbed into existing business routines without deploying additional processes or routines and can rely on existing routine operational competences. An organisation that predominantly assimilates knowledge close to its existing knowledge base/s is less likely to be engaged with radical disruptive innovations. Such firms can be prone to path dependency to known partners and are unlikely to extend their knowledge networks. Similarly, this could suggest where firms spend more time assimilating new knowledge over transformation learning activities – may imply such firms are predominantly engaged with incremental innovations that requires limited or no adjustments to internal business processes.

Assimilated knowledge seems to assist with incremental changes to a firm's innovation products. These organisations can also be prone to turbulence from disruptions in their business conditions (the market place, changing customer demands and technologies and scientific advances) and have fixed managerial cognitive learning structures. Secondly, firms that spend less time on assimilation learning activities may infer that the newly acquired external knowledge is less familiar to a firm's existing knowledge base and require developing and deploying additional processes or routines to their learning process that transforms a firm's competences.

Transformation means that new knowledge is interrelated with changing existing cognitive structures. When a firm's transformation learning activities are greater than its assimilation activities may imply an organisation is engaged with more significant cognitive demanding challenges requiring new capabilities and processes to refine and to make sense of new knowledge. This requires the firms to develop and deploy new internal businesses operational practices and routines. Hence, the transformation learning process of existing internal operations warrants significant redesign and redeployment of routines in a dynamic way. Firms that tend to engage predominantly with

transformation learning process over assimilation could indicate they extend their knowledge bases beyond what is considered certain and safe or pushed into dissimilar knowledge domains.

This finding seems consistent with Todorova and Durisin (2007) interpret assimilation and transformation as two parallel elements. Knowledge is assimilated, if the existing cognitive structure of organisational members does not change; pieces of new knowledge that are not assimilated into the internal business operations and routines requires to be transformed to make sense and be purposeful.

Knowledge pieces may move not only from assimilation to transformation processes but also in the opposite direction. For example, during change of the knowledge structures through new process implementation, organisations may repeatedly regress to learning through their prior knowledge structures and assimilation processes after the transformation process (Maritan and Brush, 2003). We propose that pieces of knowledge that an organisation tries to absorb may move backward and forward between assimilation and transformation processes before they are successfully incorporated into the organisational knowledge structures and ready for exploitation.

The transformation enables organisations to perceive new knowledge to some extent incompatible with prior knowledge, to build new cognitive structures, and to cope with path dependency. Thus, it may be the transformation capability that allows firm to survive a competence-destroying change (Tushman and Anderson, 1986). Zahra and George (2002) suggest that firms transform already-assimilated knowledge. We propose that firms transform their knowledge structures when knowledge cannot be assimilated. Transformation represents an alternative process to assimilation Todorova and Durisin (2007).

Thirdly, new knowledge that is easily assimilated into the firm infers that it is required information envisaged or deliberately sought by the firm to solve problems to existing technological 'know-what'. This seems consistent with Buganza, et al., (2014, p.78) assertion that it is relatively easy for firms to collaborate with universities on the testing aspects to the NDP process: "...SMEs are able to define their needs clearly and precisely and to assess the quality of the services that are receiving. Hence, it is easy to define such contracts with universities, which are often standard. In other words, the access and interface costs are low because the service is easily describable; buying a test service from a university is similar to outsourcing to any external company". It can also suggest that, when firms collaborate on testing aspects to the NDP process, this seems to require a lower level of project and technology management capabilities. Furthermore, it was found that, SMEs at the start approach the collaborating universities with clear and easily definable tasks (such as testing), and only after positive experiences in these collaborations do they move towards more complicated, trust-based relationships such as development and research (Buganza, et al., 2014, p.78).

Innovation and AC is a major research theme focused primarily on the utilisation (exploitation) dimension of AC. Because innovation is an outcome of organisational learning, it is not surprising that it too has a recursive relationship with AC. Prior research on this theme suggests AC helps the speed, frequency, and magnitude of innovation and that innovation produces knowledge that becomes part of the firm's AC. AC increases the speed and frequency of incremental innovation because such innovations draw primarily on the firms' existing knowledge base (Anderson and Tushman, 1990; Helfat, 1997; Kim and Kogut, 1996 in Lane, et al., 2006, p.849). A firm's Potential AC is initially captured by the issue of a patent and/or trademark to protect the intellectual property rights (IPR) of the new knowledge created. Innovations have largely been operationalised as patents (Ahuja and Katila, 2001; Sorenson and Stuart, 2000) and new products (Deeds, De Carolis, and

Coombs, 2000; Tsai, 2001; Yli-Renko, Autio, and Sapienza, 2001 in Lane, et al., 2006, p.849). During the lifespan of a patented innovation (known as the 'appropriated' or 'proprietary' knowledge of the firm), a firm will seek to achieve their Realised AC by increased market capture through the commercial exploitations of its IPR with new firm product innovations through its supply chain.

5.2.1 Firms 1 and 2

As indicated above, the smaller two firms' AC activities are dominated by Realised AC. This may indicate that the learning processes undertaken by these firms achieve a higher efficiency ratio (as per Zahra and George, 2002) to realised commercial exploitation outcomes. Their learning processes undertaken in the potential stage appears less intensive with respect to each of their perspectives of their product innovation success. These firms have presented evidence of a consistent focus on business activities that assimilate and/or transform newly acquired knowledge through changes made to their established business operations and routines. This is reflected in the shorter timeframes between when the firms acquired new knowledge and achieved a new product outcome (product innovation). The first two firms generally produced wider incremental innovation products that were less radical or disruptive in nature to the market and quicker to commercialise to achieve an economic return related to their technology adoption and R&D investment.

This reflects the view that AC increases the speed and frequency of incremental innovation because such innovations draw primarily on the firms' existing knowledge base (Anderson and Tushman, 1990; Helfat, 1997; Kim and Kogut, 1996 in Lane, et al., 2006, p.849). This could be attributed to a thinner supply chain, with less rigidity in terms of specific detail customer requirements and level of commercial risks. AC has commonly been operationalised in terms of knowledge content (i.e., patents), it is not surprising that several studies have shown significant support for the hypothesis that AC positively affects innovation. This finding is consistent with the argument that incremental innovations are best supported by an AC that provides a deep understanding of a narrow range of closely-related knowledge domains and assists in increasing that depth (Van den Bosch et al., 1999 in Lane, et al., 2006, pp.848-850).

The role and contribution to the depth and breadth of external knowledge sources and innovation important is important component to a firm's AC (Ferrerias-Méndez, Fernández-Mesa, & Alegre, 2016; Ferrerias-Méndez, Newell, Fernández-Mesa, & Alegre, 2015) first introduced by Laursen and Salter (2006). Laursen and Salter (2006, p.134) introduced two terms to define the openness of firms' external search processes. The first concept refers to external search breadth, which is defined as the number of external sources or search channels that firms rely upon to improve their knowledge base, whereas the second concept refers to external search depth and it is defined in terms of the extent to which firms draw deeply from the different external sources to increase performance. Leiponen and Helfat (2010) conducted one of the first firm-level statistical analyses of the impact on innovation of breadth in both innovation objectives and knowledge sources. Their empirical results suggest that broader horizons with respect to innovation objectives and knowledge sources are associated with successful innovation. "*We do not find diminishing returns to breadth in innovation*

objectives, which suggests that firms may tend to search too narrowly" (Leiponen and Helfat, 2010, p.224).

The empirical results suggest that greater breadth of innovation objectives and knowledge sources is associated with greater innovation success at the firm level, particularly with regard to the 'value' of newly commercialised innovations in terms of sales revenues. The analysis controlled for important factors that could affect innovation success such as research funding and capability, and, in a robustness analysis, showed that individual objectives and sources were not consistently significant predictors of innovation success. We also found generally increasing returns to a greater number of objectives and sources. Diminishing returns set in only at a relatively large number of sources, again supportive of the benefits of breadth. Finally, we found no evidence of a positive interaction of breadth in objectives and sources (Leiponen and Helfat, 2010, pp.234-235).

When discussing the firm's external network with the owner of the first firm, it became apparent how over time this firm has systematically orchestrated a well-defined and closed innovation system (network) between its suppliers (both fibre providers and the knitting textile manufacturers) and the University research sector. *"It's a pretty complicated system though isn't it when I think about it all the way through. We've got very good relationships with them all. I'd say the operation guys, they meet with the people that produce the yarn..., and then the knitters and finishers, there's different finishing houses that wash and do everything. There are little things that get added on; like we've now got a thing that goes into the lining. It helps with the 'wicking', it tends to keep you cooler, stops that smell from sweating and all that sort of stuff. These are just little add-on things we're doing all the time."*

As such, the adopted technology applications are less risky and modest and consist of a mixture of symbolic and synthetic knowledge bases driven by end DU&I user ('market pull') considerations such as aesthetics, comfort and other personal hygienic requirements less dedicated by rigid industry OEM standards and the like. Both firms have benefited from several years of previous product innovation success; building up to a suite of products as part of a continual long pipeline ('roll-out') of new products. In the case of the first two firms, the technology that these firms rely upon and exploit have been refined to the extent to which their commercial applications are more incremental, occur more frequently, and take less time to develop for commercial applications to achieve product innovation traction success.

For its technological developments with NPD the first two SMEs are more wedded to the University, and it follows that they were more reliant on closer physical and cognitive proximity ties for the exchange of tacit knowledge. This is the case where the General Manager of the second firm is based at the Geelong Technology Precinct (GTP) on the University campus to work alongside University researchers. Furthermore, the University has benefited from its researchers attending the firm's international operation headquarters in Switzerland. Firm one has benefitted from a University industry researcher working within the business to glean knowledge of its local and overseas operations with its global supply chain. The University has also benefited from transfer of knowledge from the firm to its research program, and has forged relations with the supplier of the firm's fibres (DuPont)

5.2.2 Firms 3 and 4

The AC activities of the larger two firms resonates the greatest in the Potential AC stage. Conversely to the smaller firms, these firms have thicker and deeper value and supply chains – particularly when working with commercial applications of the technology for global OEMs, such as aerospace and automotive customers. The application of the firms' technology needed to meet the overall design specifications to accord with a customer's engineering design for a new product. Working with OEMs depends upon the technology to produce specific componentry parts at required production volumes, whilst meeting high quality design and performance standards. The firms needed to demonstrate they could deliver these products by adopting advanced automotive processes to ensure reasonable returns of investment, and to ensure economic value for the new technology adoption.

The larger two SMEs, in contrast to the first two firms, tend to spend more of their learning processes undertaken in the Potential AC stage. This is concerned with intensive activities that are associated with the longer qualification times it takes to explore and prove its technology to the requirements of preferred suppliers such as OEM customer, which occurs largely in the assimilation and the transformation stages. In terms of the respondents, there is less narrative on its focus and activities relating to transformation and exploitation. As raised before, this is due to the lengthy timeframes required to explore technology to discover its commercial market applications and the radical nature of their innovation product outcomes to its niche global automotive and aerospace OEM customers. Consistent with the findings of Aribi and Dupouët (2016, p.22), these firms pursue 'new-to-the-world' innovations in areas of high technologies. The greater complexity of products requires firms to be prepared to take the risk of the greater uncertainty regarding what knowledge is necessary to complete the project. This leads to a longer transformation phase.

Both firms have invested heavily into the automation of their factory processes by adopting 'smart factory' manufacturing and technological capabilities associated with robotics and decreasing manual handling. The firms place a high impetus on deploying advanced manufacturing techniques through its internal R&D capacity of highly trained and skilled staff, its University research collaborations, and other external networks and partners globally. These firms' technology is heavily driven by a combined applied analytical and synthetic knowledge applications (ST&I plus DU&I learning). This is driven by both 'market' and 'technology push' considerations of specific scientific and engineering industry standards for structural design integrity of the product.

The DU&I mode of innovation depends on a synthetic knowledge base and on learning by interacting between the deeper supply chains of both firms; as an example: between a company and its specialised sub-contractors and its customers. It is a more demand-driven innovation model than ST&I and is particularly useful in analysing incremental innovations in industries such as mechanical engineering. The model is particularly useful for analysing a science and technology push or supply-driven innovation processes. Other examples include the biotechnology and nanotechnology

industry sector, which require regular industry-university links and respective networks, with more frequency than in other types of knowledge bases (Asheim, et al., 2011; and Dutta and Hora, 2017).

Apart from their size and dedicated R&D staff, the larger two firms rely heavily on engineering disciplinary practices associated with engineering project management documentation standards and techniques, which assists internal management activities and processes. The innovation pathways for these two firms are longer, with learning processes during the Potential AC dominating over the Realised AC learning processes. This could be attributed to the more radical innovation nature of their new knowledge and technology and longer gestation period from laboratory to full scale manufacturing industrial production stages. Some have suggested that radical innovation involves novel combinations of existing technologies and know-how (Kogut and Zander, 1992; Van den Bosch et al., 1999).

Similarly, the magnitude of innovation could have implications for a firm's future AC; a revolutionary innovation is likely to create AC in valuable new areas. Developing routines that enhance resource re-combinations and knowledge complexity (Galunic and Rodan, 1998; Van den Bosch et al., 1999) enables a firm to recognise and assimilate more complex knowledge from external sources. In other words, radical innovation is best supported by an AC based on a broad range of loosely related knowledge domains and helps to further increase that breadth (Van den Bosch et al., 1999). Given the relative paucity of studies specifying explicit mechanisms for integrating and exploiting such loosely related domains, very rarely has the relationship between AC and radical innovation been examined (Van den Bosch et al., 1999 in Lane, et al., 2006, p.850).

5.3 Data Analysis of each Firms AC

In terms of AC construct and its relationship to exploration and exploitative innovation learning processes (and the many sub-dimensions attributed to these four dimensions), the data from this study reflects aspects of previous empirical research AC model findings – (Lane, et al., 2006; Todorova and Durisin, 2007 and others summarised in table 5); however this study would suggest the following observations that contribute to the study of AC models.

5.3.1 Acquisition (Exploration)

AC 1 Acquisition learning process entails both scan and search activities that can be narrow or broad, depending on the nature of the firm's knowledge and technology base, as well as its supply chain networks (such as existing and potential new customers and suppliers). This process drives each firms' exploration learning activities and dominates the Potential AC stage (37 percent of 49 percent) leaving AC 2 assimilation (12 percent) playing a less significant role for each firm, as shown in tble 33.

Table 33: Role of AC 1 Acquisition across all Firms in Potential AC

AC Stages	Firm 1 (%)	Firm 2 (%)	Firm 3 (%)	Firm 4 (%)	Total (%)
AC 1 Acquire	32	33	49	42	37
AC 2 Assimilate	14	10	15	12	12
Potential AC	46	43	64	54	49

Acquiring new knowledge involves the antecedents of inter-organisational learning along with the cognitive nature and style of managerial conditions (Volberda, et al., 2010) and so reflect several meta-routine business activities across a firm's external innovation capabilities (Lewin, et al., 2011). Acquisition learning activities should be considered a deliberate, regular and ongoing process within an organisation. It is evident from all firms the processes of absorbing new knowledge from external sources occurs largely through all AC phases; it tends to be initially greater at the acquisition phase for all firms and then again at the transformation phase when firms need expert specialised input to solving very specific problems that deal with issues needed to advance the firms initial proprietary technology. Acquisition of knowledge appears to be more intensive during the exploration phase for firms three and four, than exploitation from this study's findings; these firms deal with greater knowledge complexity due to the radical disruptive nature of its new product developments.

The level of investment in the scan / search activities to identify and acquire new knowledge varies throughout the innovation process. Acquisition learning processes is also essential prior to end of a product range to ensure continuity of innovation pipelines and streams of new products. This is more relevant for traditional R&D activities. A greater emphasis on non-R&D activities such as marketing and social networking seems to occur in the Realised AC stage. As such feedback loops exist both in the exploration phase (AC 1) (between recognition and acquisition) prior to assimilation and between exploitation (AC 4) and exploration (AC 1) to support Aribi and Dupouët (2016) findings. The two smaller SMEs incorporate existing and mature technologies in their products. The larger two firms are driven to engage in new knowledge and products development due to its customer demands.

The larger two SMEs and to a lesser extent the second firm are required from their customers' 'new-to-the-world' products. This technological knowledge is not accessible 'off the shelf', firms three and four will engage in additional feedbacks loop in the exploration phase to construct the new knowledge to meet the necessary technology to fulfil the customer's demand. It is thus necessary to access fundamental research in order to elaborate on the concepts that could be incorporated in the final product. Here, the firm must engage in a discussion with the University staff with respect to industrial constraints such as the required outputs, delivery time, budgets, and formal collaborative partnering arrangements. This phase demands several interactions, such as project meetings and the like to engage the firms existing knowledge operations and routines converge to build a common understanding of what could be done to derive with a possible technological solution/s.

Several authors have elaborated on the importance of deliberate learning process firms need to develop across the AC process. Berghman, Matthysens, Streukens, and Vandenbempt (2013) have argued the importance of continuously reinventing business models and creating new customer value. They extend these views by focusing on the impact of deliberate learning mechanisms (Zollo & Winter, 2002) on an organisations strategic innovation capacity. Berghman et al., (2013) re-interpret AC through a cognition lens to apply a PLS analysis on survey data suggests that strategic innovation capacity is strengthened when managers deliberately install specific learning mechanisms on the three dimensions of AC: (i) knowledge recognition, (ii) assimilation and (iii) exploitation. Results complement existing research by indicating the importance of deliberate action when trying to break through existing industry practices.

Similarly, Jensen and Clausen (2017) identified successful new technology-based firms (NTBFs) that developed their organisational capabilities for exploration and exploitation and, in particular, the role of routines for deliberate learning in this regard. In short, they found support for all hypotheses; we also saw that the direct effect of behaviour on capability emergence became non-significant for exploration behaviours, providing evidence for the need for routines for deliberate learning for the emergence of exploration capability. While this was not the case for exploitation behaviours – indicating that exploitation behaviours would develop organisational exploitation capabilities on their own – *‘we did observe that the exploitation behaviours and routines for deliberate learning were more effective in combination than on their own.’* Our model and empirical results have addressed this issue in the context of NTBFs, a type of firm that are, by their nature, closely aligned with innovation search. *“Importantly, we show that firm heterogeneity in exploration and exploitation capabilities forms early in the life-cycle of new ventures.”*

5.3.2 Assimilation

In contrast to the Patterson and Ambrosini (2015) study, the role of assimilation is weaker and less observable in this study’s data. This study would concur with the premise identified by the Patterson and Ambrosini study that assimilating external knowledge after its initial acquisition occurs and requires *“continuous assimilating capabilities throughout the ‘transform’ and ‘exploit’ process components.”* Except for the first firm, the balance of SMEs in this study mirror the assimilation experiences of the firms in Patterson and Ambrosini study; this indicates ‘assimilate’ occurs before and after the ‘acquire’ activities. The distinct difference in the assimilation of new knowledge identified in this study in comparison to Patterson and Ambrosini (2015), is that most SMEs in this study develop their own IPR using external knowledge sources such as partnering universities. The only minor variation occurred with the second firm, which initially acquired new knowledge in the form of technology licence from the University and a spin-off company (Cytomatrix P/L). Through this firm’s internal capacity they have been able to advance the scale of the technology for commercial industrial applications in collaboration with the University and its allied partners.

The second firm's knowledge base has some similarities to the biotechnology firms in Patterson and Ambrosini's study in that they assimilate new knowledge usually in the form of a licence or acquiring another firm's IPR to a biologic or new chemical entity. In the case of the second firm, the acquisition and assimilation of new knowledge acquired from Deakin University did not transpire as a direct result of deliberate opportunity screening, due diligence or assessment activities as part of the 'assimilate' component of acquiring new knowledge. The assimilation of the newly acquired knowledge and associated technology for synthesising SPFs was the key stage in this firm's AC. The assimilated new knowledge acquired from the University's research formed a critical missing piece of information that helped solve an existing business problem the firm had with using SPFs as surface treatments to textiles for potential range of commercial applications.

This work extends the research output developed by the University originally with Cytomatrix and Austeng. The firm worked closely with Cytomatrix that represents a traditional business to business licensing arrangement. It developed a separate collaborative research program with the University to extend the firm's acquire SPFs technology. This firm has developed its own new technology through its collaborative with the University as part of a series of research collaboration agreements. The assimilation of the newly acquired knowledge by firm two did not engage in lengthy assimilation learning activities outlined in the Patterson and Ambrosini study.

As discussed by Patterson and Ambrosini, firms will – either by directly acquiring IPR and refining it and/or develop their own new IPR – need to gather and transfer the IPR data from between sending and receiving parties. Internal process to firms will oversee the initiated agreed phase of product development. Information from both parties needs to be organised and assimilated into each other's internal processes. This requires capable alliance/collaboration management and project management skills to facilitate the initial project set-up and information transfer. If the project is executed in an alliance and in an open innovation configuration the new NPD process can last many years and the transfer of information between the two parties jointly developing a product occurs throughout, as described in Zahra and George's (2002) transforming external knowledge process. The acquiring / absorbing firm needs to be continually assimilating external information for successful product development. Thus, assimilate does not stop at the acquire phase and continues after the acquire process. This indicates that the 'assimilate' component is a neglected, but very important component of AC in the literature (Patterson and Ambrosini, 2015, p.84).

5.3.3 Transformation

Similar to the other AC models discussed in this thesis, this study's findings resemble observations made of the sequence and timing of the transformation phase. The Patterson and Ambrosini study revealed that 'transform' does not occur in a sequential order after 'assimilate' as suggested by Zahra and George (2002), but rather, it is iterative process that flows with 'assimilate after acquire' and 'exploit'. Todorova and Durisin (2007) also proposed an iterative process relationship between 'assimilate,' 'transform' and 'exploit,' but the Patterson and Ambrosini study is the first to provide empirical process evidence for it. Furthermore, this is supported again by Aribi and Dupouët (2016,

p.21 and pp.22-23 identified two feedback loops: (i) a feedback loop in the transformation phase (AC 3) (between assimilation and adaptation); and (ii) one between transformation (AC 3) and exploration (AC 4).

This thesis suggests transformation is a critical phase to a firm's AC, particularly to achieve Realised AC, as indicated in table 34. This is largely the necessary precondition to capture value from its IP, and the firms need to add value to it before it can achieve commercial success and broad adoption of its technology output. This was made evident by the Patterson and Ambrosini study – and for the most part is required to get the firm over the 'valley of death' – a common phenomena many R&D intensive can firms face. Whilst firms have expended much effort – resources and time (financial and human) to arrive at pre-commercialised stage, a firm's AC must be sufficiently developed to achieve economic gain. This is ultimately the end goal of their innovation journey to achieve, maintain and sustain a competitive advantage.

Table 34: The role of Transformation AC 3 to Realised AC

AC Stages	Firm 1 (%)	Firm 2 (%)	Firm 3 (%)	Firm 4 (%)	Total (%)
AC 3 Transform	18	28	12	21	22
AC 4 Exploit	36	29	24	25	29
Realised AC	54	57	36	46	51

Transformation occurs for all firms and tends to form a greater effort and role across the larger two SMEs in this study. These firms develop IPR to radical disruptive new knowledge and technology which has been the cumulative effects of the firms AC. All firms have achieved a 'theoretical' Realised AC by deriving at product innovations through the NDP process celebrated by a high appropriation regime in the form of patents. At this point, it's imperative for this success to be captured by commercial success in the market place. In the case of the first two firms, they produce a finished product that is then supplied directly to customers for retail or wholesale bulk sale. In the case of the second firm, a finished synthesised SPF material is supplied to manufactures requiring specific treatments to fibres for textiles that are used by wide range of end clients. In both cases there is limited evidence gathered to explore if and how these two firms work with or tailor their product innovations to their customer base. There is less formalised organisational learning needed to achieve their commercialised Realised AC.

This is not to infer new knowledge does not feed back into these two firms from customers, adding to their continual incremental product development. When it does, such new knowledge is assimilated relatively easily. It does not require the firms to expend energy and time to transform its process. These firms largely self-develop through their own internal goals for continual NPD as part of a pipeline of products and investment into R&D, such as the research partnerships it has entered with Deakin University. In this transformation phase the collecting learning and research partnerships in collaboration with the University are critical to ensuring its IP is commercialised. This involves

discrete research projects managed by the firms with the University; and may involve such initiatives as the use of PhD research students and post-doctorate University projects. For the most part, the details of this new knowledge creation process are not readily available for this study. However, this was seen in the case of previous collaborative outcomes, such as several joint initiatives between the firms, the University and global OEMs in the automotive and aerospace sectors.

A loop during the transformation phase (between assimilation and adaptation) occurs when firms further elaborate on the knowledge they need to build the targeted product. The knowledge managed becomes less and less conceptual and increasingly practical and applied. *In the studied firms, this knowledge is mostly technological, and firms aim to create connections between the newly acquired knowledge and existing knowledge. The transformation phase lasts about 4 months in firm 3 whereas it may last up to 5 years in the two other firms* (Aribi and Dupouët, 2016, p.21). The difference is due to the complexity of the product developed in these two firms, as well as the nature of the innovation pursued. These firms pursue 'new-to-the-world' innovations in areas of high technologies, the greater complexity of products and the greater uncertainty regarding what knowledge is necessary to complete the project results in a longer transformation phase. However, apart from this important difference, the process is similar in all studied firms.

Once the decision has been made to develop a new product based on a body of new knowledge, firms assign individuals to that specific task. These individuals will then engage in a collaborative process. Our respondents identify two major ways of doing this. Either they recruit specialists with the required expertise and/or they train employees in the area of interest. In project teams, specialists of new and old knowledge domains bring their experience and know-how. The constant interactions over a long period of time between individuals are a source of collaborative and common knowledge building. For this process to be successful, all our respondents stressed the role of trust, and especially professional trust, which has to be built in each project team. The process will deliver the expected outputs if members of the project team are confident that their colleagues are skilful professionals and that they know what they are doing. Hence, in the transformation phase, intense social exchanges enable the co-evolution of new and existing knowledge to come up with new knowledge combinations incorporated into the products. The output of this phase is either an early prototype or a model that will then be completed to form a product that could be delivered to the market (Aribi and Dupouët, 2016, p.21).

The transformation learning phase is critical for the large two SMEs in this study. These two firms pursue ongoing transformations of their internal operations to exploit their technology 'know-how' to achieve Realised AC. This is dependent upon working on commercialisation opportunities in the form of firm sponsored or joint project demonstration development work with customers such as global OEMs (that may or may not involve the University). Upon entering a NPD project with an OEM it has a long lead time to qualify its technology and demonstrate it can produce component parts to meet the production processes of OEMs. Such demonstration projects form a further qualification learning

process of the firm's technology to fully realise its commercial potential. This therefore involves a continuous investment into the firms AC. The firms are required to furnish their unique knowledge and technology 'know-how' to targeted industry acceptance and application in final production and of finished products by manufacturers such as global OEMs.

The experiences of the two larger SMEs are similar to the biopharmaceutical firms examined in Patterson and Ambrosini (2015, p.85), where transforming external knowledge occurs when a firm, either alone or with a partner company, discovers, develops or commercialises owned or licensed IPR. In this way, the firm adds value to the IPR to out-license or fully commercialise the higher value added IPR. The 'transformation' component phase can take from a year to five or more years depending on the maturity of the IPR asset and length of time of the agreed co-development. There are two important findings coming from their study's coding:

- The first is that developing the drug with a collaboration or alliance partner means that assimilating external information occurs throughout the 'transform' component activities.
- The second is that transforming external knowledge with an external partner company requires additional firm level capabilities of alliance and/or collaboration management and project management capabilities to enable successful conclusions.

The third firm, as an example, developed a highly capable group of skilled staff for specific skill sets. Having the right people in place was imperative for this firm and each member of the executive team brought decades of know-how from the aerospace, automotive, and composite industries. The firm has a diverse set of skills across mechanical and software engineering, business management, supply chain logistics, and assembly, and places an emphasis on teamwork, accountability, and communication. This firm adopts a modern engineering approach like that of an aerospace contractor or premium automaker. In fact, several of their staff previously worked on Boeing's composite projects. *"With us, we break down the wheel into an assembly, so it's a whole different set of subsystems,"* Denmead says. *"We have our material system that incorporates all the materials that we use, so what we actually have is a validation plan for introducing new materials."*

One key individual that forms part of a small diverse team of executive managers is Brett Gass, Executive Director at the company. Gass was a driving force behind winning Ford's confidence in 2012. As a former Ford Australia engineer who had stints in Europe and America, he was responsible for chassis development on some of the brand's best-selling sports cars and SUVs. *"Jake and I would do road trips over the years around the world and would first introduce OEMs to the fact that carbon wheels are possible and exist,"* Gass says. The relationship with Ford was a natural fit. *"I moved to Europe because we thought we'd attack Europe first. We were very active in Europe. Ford was one of the later OEMs we contacted, but they wanted to innovate and take the Mustang to new levels of performance."*⁴¹

⁴¹ <http://www.motortrend.com/news/carbon-revolution-rethinking-wheel-aussie-style/> published 14/12/2015.

Transformation can occur as a separate process altogether as either a substitute to assimilation altogether; or in part after the assimilation phase, and prior to the exploitation stage. This can depend on the complexity of knowledge and the complementarity of it to the firm's existing knowledge stock and business routines to apply the new knowledge. Transformation phase involves regular feedback loops to exploration as firms continue to enrich, add to, and enhance their knowledge as NPD projects moves forward. In addition to internal development, it may be necessary to go back to the exploration phase, that is, acquire additional knowledge in the environment. This stems from the fact that the necessary knowledge cannot be completely determined beforehand and that it is necessary to complete these as the project becomes increasingly formalised and structured. In order to gain access to the necessary complementary knowledge, firms must set specific channels to external knowledge sources. These loops are different, depending on whether we consider the first two firms or the last two firms.

For the first two firms, in which projects are on a comparatively smaller scale, the external knowledge sought is mostly technological. The business idea is not questioned at this stage. Further, the access to this technological external knowledge takes the form of punctual contacts with identified individual experts, constituent to Aribi and Dupouët (2016, p.22). These firms develop strong network ties, based on dyadic trust, with these University experts. When necessary, they can be called in for short periods of time to solve specific problems. It is also common to train project team members on the fly, whenever the need is felt to acquire a new technique or some specific knowledge on a particular technical aspect. Training is ensured by partners or even customers, depending on the competency sought.

In the case of the last two SMEs the many feedback loops between phases when additional information is required often involves testing and validation of various materials through the use of the University's research facilities and staff. In the case of the last two firms this will occur until their technology meets its OEM customer requirements triggering a continual exploration processes to acquire new knowledge to advance the evolution of its new 'know-how'. This is required to supplement the firms' proprietary knowledge, such as material characterisation and refinement of chemical resins used with carbon fibre materials. The material characterisation of carbon fibre production processes needs to be scientifically tested and validated to qualify the materials before it proceeds to its exploitation stage and used in production.

Specifically, Aribi and Dupouët (2016, p.22) identified a loop between exploitation and transformation where firms are more reliant on its customers broad markets than specifics of detailed technical requirements – as seen in the smaller SMEs of this study. This occurs for the first firm with its variations of its aesthetic designs for its fashion markets in Europe and the US, whilst its technical specifications to its protective and safety dimensions remain universal across its product innovations. Similarly, the second SME launches its product to many customers across its different markets. This is achieved through demonstration workshops with existing and potential new customers, where

feedback maybe sought for refinement of its fibre treatments and potential commercial applications. These scenarios are similar to those reported by Aribi and Dupouët (2016, p.23) where...*the different actors involved in the exploitation phase, in particular salespersons, have to be convinced of the value of the newly introduced product. They have to understand it to incorporate it into their product portfolios. A negotiation thus takes place, and, if salespersons are not convinced by the new product, they may ask for major changes. When concerns raised by production or the sales departments are so serious that they cannot be solved by making minor changes to the final product, it is then necessary to return to the transformation phase.*

Unlike the two smaller SMEs, there are no loops between exploitation and transformation for the third and fourth firms. This reflects the process outlined by Aribi and Dupouët (2016, p.23), where products to be developed are complex and project durations are long. In this case there are two kinds of knowledge learning loops firms will undertake. First, these firms regularly check with customers that the project is well in line with what was initially specified. This means going back to customers, inviting them to internal meetings, and setting regular check points. It may even entail the hiring of customers to guide the transformation process. The length of this first kind of feedback loop is determined as necessary by nature of the projects and the associated risk of diverging from initial demand. In addition, the length of the transformation phase implies that new knowledge not existing at the start of the project may emerge in the environment, the incorporation of which in the project must be discussed with the customer.

Secondly, for firms engaged in disruptive innovation process, technological and scientific knowledge needed for the development of the new product cannot be fully specified predicted beforehand. The need to go back to a more conceptual level is even greater than for firm the first two SMEs. Consequently, larger firms maintain ties with external research centres during transformations because uncertainty is high and the number of issues to be dealt with is important. These firms tend to develop long-lasting ties with external parties. These ties usually take the form of formal partnerships and imply a continual involvement of the external partner until conceptual aspects of the new knowledge area are fully understood.

5.3.4 Exploration

Again, consistent with previous AC models discussed, this study's findings show that exploitation does not always occur in a sequential order after transformation, as implied by Zahra and George (2002). Similarly to Patterson and Ambrosini (2015) and Todorova and Durisin (2007), the transformation-exploitation sequence involves an iterative relationship between 'assimilate,' 'transform' and 'exploit,' For 'exploit,' the time duration can last from six months to many years for the firm to develop, refine, extend or leverage capabilities. In an open innovation context, this is done mostly through learning what the other partner does. As discussed by Aribi and Dupouët (2016, p.23), they identified a loop between exploitation and exploration where – once the absorptive process is completed, created, and agreed on – knowledge (research articles, patents, industrial processes, etc.) will be codified and guide future absorptive endeavours.

Aribi and Dupouët (2016) identified two feedback loops involving the exploration process. The first within the exploitation phase – between what they label as ‘completion and application’; and the second loop between exploitation’ (AC 4) and exploration (AC 1). Exploration sees firms achieving commercial success and economic gain from industry applications of their technology. Firms in this phase deliver to the market place a successful new product. As discussed in the case of the first two SMEs, they achieve commercial output quicker and make new products available without requiring major additional feedback loops to acquire, assimilate, and transform its technology to clients. The technology platforms associated with last two firms are less adaptable for its targeted global OEM clients. This sees both firms engaged with iterative feedback loops between acquire-assimilate and/or transform-exploit-acquire. This phenomenon reflects the complexity of knowledge associated with the technology platforms of the larger two firms and the ‘irreversibility’ of the AC process necessary to meet customers’ specific product requirements.

Irreversibility is thus probably not as important as these previous models suggest; rather, it is important that firms maintain some degree of flexibility in the process. It seems that this flexibility is necessary to guarantee the alignment of the knowledge and product produced with the requirements of the other parts of the organisation as well as with outside partners and customers. It enables firms to avoid tunnel effects or overdue investments in a solution that would turn out to be a dead end Aribi and Dupouët’s (2016, pp.23-24).

There are a certain number of knowledge bases, along with search engines, that employees are required to fill in. In addition, employees are encouraged to produce codified knowledge to make results and outputs visible. This takes the form of articles published in scientific or professional journals, communications within industry conferences, and so on. This loop thus enables firms to refine and extend the newly acquired competencies and lay the groundwork for the next exploration round. Furthermore, knowledge and technology should continually be refined once it reaches commercialised product output, and ultimately, be recorded as part of the firm’s internal knowledge stocks to become codified knowledge. This allows wider knowledge diffusion to open innovation channels to outsiders, to stimulate incremental changes in the original knowledge and technology. The only limitations to this are IP rights; the appropriation regimes put into place by the firms and the business innovation models they adopt. The weakening or loosening of high IPR barriers comes after several years once the firm has cemented its early mover advantage/first entry position in the market.

5.4 Sequential Organisational Ambidexterity

March (1991, p.102) proposes that exploitation and exploration are two fundamentally different learning activities between which firms divide their attention and resources. Whereas Potential AC espoused by Zahra and George (2002) consisted of the AC phases of acquisition and assimilation or broadly the exploration stage, and Realised AC consisted of assimilation and exploitation (commercial applications) to represent the exploitation stage. Exploration refers to notions such as ‘search, variation, experimentation, and discovery,’ whereas exploitation is associated with learning activities such as refinement, efficiency, selection, and implementation. Exploitation and exploration may therefore require fundamentally different organisational structures, strategies, and contexts. Several scholars maintain that there is a trade-off between aligning the organisation to exploit existing competencies and exploring new ones (Raisch & Birkinshaw, 2008).

Ultimately, a highly competent firm needs to transition through each AC phase and, at times, back and forth between the two key AC stages of exploration and exploitation learning. For a firm to achieve commercial application and value from its exploration of new knowledge and technology, the pivotal transitional points occur in either the assimilation and/or transformation phases before it can exploit wider applications of its knowledge platforms. The merits of organisational ambidexterity provide credence to achieving a balance among the component capacities (assimilation and transformation) of AC. Zahra and George's idea of the importance of a 'high efficiency factor', where Realised AC approaches Potential AC, can be further elaborated in terms of the importance of a balanced development of all four component capabilities. Contrariwise, firms can possess a strong capability to identify new knowledge and a weaker exploitation capability, which causes them to fail to translate new knowledge into new products and processes (Todorova and Durisin, 2007, p.780).

The distinction between exploration and exploitative learning processes is an important one to note, for firms need to develop capabilities across both to achieve Realised AC. Lubatkin, Simsek, Ling, and Veiga (2006) defines exploration as a bottom-up learning process; exploration are those activities that enable active response to changes in the environment by carrying out revolutionary innovations. Exploitation involves a top-down learning process to involve carrying out activities related with refining the existing technological or marketing trajectories that attempt to adapt to the conditions of the environment and the firm's customers. It is measured as exploitation orientation. Daneeles (2002, 2008) adds that a firm's innovation capabilities activities can be first-order or second order; given the nature of dynamism that is either considered everyday routines or newly developed routines to deal with the extent of changing business conditions and market turbulence. Gibson and Birkinshaw (2004) conceive exploration and exploitation as capabilities of adaptation and adjustment.

1. Adaptation capabilities: management systems that encourage individuals to change their traditions and practices that are flexible so that they can respond quickly to changes in the market, and that evolve quickly to adapt to changes in business priorities.
2. Adjustment capabilities: management systems that work coherently to support the goals of the organisation, that endeavour not to waste resources on non-productive activities, and that do not propose conflicting goals.

The greater the novelty value of the firm's innovations determines the extent of potential market disruption and the level of change – either incremental or radical innovation outcomes. As identified in this study, the first two SMEs proceed with less disruptive innovations, which are incremental advances of an established technology platform the firms have developed and continually add value to. The larger two SMEs operate at a higher novelty value seeking to trigger a market disruption in its respected targeted industry sectors. As such, the radical innovations are risky and require longer timeframes in the assimilation and transformation phases to create a return from its original R&D outlay, and before the innovations can contribute to added valuing explorative processes to create an ongoing continuous product pipeline and revenue stream.

In the case of the two large SMEs, the third firm – with its single multi-faceted technology platform and product innovation output – benefits from the pursuit of a narrower product range. The firm captured value on its initial IPR and persists with diversifying the application of its innovative product to more global automotive OEMs. The firm has yet to achieve its full expected production volume capacity in Australia, which is predicted to be reached by the 2021-2022 financial year. In the interim, it has started a diversification strategy by expanding its know-how into other products that will benefit from carbon fibre wheel technology. This involves exploration of new technology processes to apply carbon fibre composite construction to other transport modes such as aircraft. The fourth firm has a legacy of innovative technology development for curing and processing carbon fibre composites for use in the automotive and aerospace sectors. Its proprietary technology has not been fully realised for the large commercial contracts needed to generate the income stream anticipated when the firm achieved the OEM qualification approvals. Those approvals were the first requirement for the firm to advance with larger commercial production volumes of parts for its targeted global OEM potential customers.

Moreover, the first two firms have a higher efficiency rate with larger proportion of their AC spent in the Realised stage, as compared to firms three and four. Firms three and four spend proportionally larger amount of time acquiring new knowledge in the Potential AC stage leaving exploitation processes somewhat lagging behind the first two firms. This time lag is attributed to the effort expended in knowledge acquisition routines, which has three attributes that can influence **intensity, speed, and direction** that is pursuant to the core tenets of AC – namely acquisition of knowledge as discussed by Zahra and George (2002, p.189). Zahra and George (2002, p.189) highlights intensity and speed of a firm's efforts to identify and gather knowledge can determine the quality of a firm's acquisition capabilities. The greater the effort, the more quickly the firm will build requisite capabilities (Kim, 1997a,b). Obviously, there are limits to a firm's ability to achieve this speed, because learning cycles cannot be shortened easily and some of the resources needed to build Potential AC are not quickly assembled (Clark and Fujimoto, 1991). The direction of accumulating knowledge can also influence the paths that the firm follows in obtaining external knowledge.

These activities vary in their richness and complexity, highlighting a need to have different areas of expertise within a firm to successfully import external technologies (Rocha, 1997 in Zahra and George, 2002, p.189). Aribi and Dupouët (2016) adds flexibility to the AC concept which helps the speed, frequency, and magnitude of innovation and that innovation produces knowledge that becomes part of the firm's AC. Irreversibility is thus probably not as important as previous models suggest; rather, it is important that firms maintain some degree of flexibility in the process. It seems that this flexibility is necessary to guarantee the alignment of the knowledge and product produced with the requirements of the other parts of the organisation as well as with outside partners and customers. It enables firms to avoid tunnel effects or overdue investments in a solution that would turn out to be a dead end.

The study's data findings seem to be consistent with other researchers that cite that firms learning activities inherently relate to different combinations of the four stages of AC, to principally involve different combinations of three dominant key stages in the AC construct. This case study concurs that the firms AC learning activities will lean towards either one of the two predominant three step/phase AC process from the four available steps originally introduced by Zahra and George (2002). As such, the first two firms are aligned with the **AC 1 - AC 2 - AC 4 sequence** or the **AC 1 - AC 3 - AC 4 sequence** in case of the larger two firms – see table 35 below. Therefore, in the case of the firms investigated, the first two firms adopt a sequence of AC learning processes principally following 'AC1 - AC2 - AC4' and the last two SMEs principally following 'AC1 - AC3 - AC4' to reflect AC models identified by Lane, et al., 2006 and Todorova and Durisin, 2007. In the case of the first two SMEs, this study supports the view that traditional innovation originates from interactions between *exploratory, assimilative, and exploitative learning processes*, whereas the last two SMEs represent firms dominant by *exploratory, transformative, and exploitative learning processes* to trigger strategic innovation. Specifically, transformative learning processes seem to play a key role when it comes to achieving new business models, radical leaps in customer value, and uncontested markets associated with strategic innovation (Gebauer, et al., 2012, p.71).

Table 35: Characteristics of Firms AC

Firms	AC Learning Process Sequence Identified	Models	Remarks
1 - 2	'AC1 - AC2 - AC4' – Realised AC Dominance	Todorova and Durisin, 2007	<p>Realised AC dominants over Potential AC to reflect less time required to explore to identify and acquire new knowledge and shorten timeframes for firms to achieve realisation of its AC. This could reflect Zahra and George's (2002) efficiency ratio.</p> <p>The firms' exploitation learning processes and routines a higher efficiency ratio between exploring and exploitative outcomes – that is they derive product innovations quicker through the NPD process and can realise a variety of commercial applications of its innovation in form of a range of products.</p>
3 - 4	AC1 - AC3 - AC4' – Potential AC Dominance	Lane, et al., (2006) Todorova and Durisin, 2007	<p>Potential AC dominants over Realised AC to reflect the greater efforts/routines and times spent with exploring new knowledge sources. Firms three and four seek to develop disruptive technologies to create radical innovations to allow light weight construction materials to be applied across several industry sectors using advanced technological methods to apply carbon fibre composites.</p> <p>Due to the radical nature of these firm's knowledge and technology bases progress through the NPD process is much slower compared to the first two firms before they can realise a variety of commercial applications of its technology.</p>

5.5 Potential AC Model Derivatives

These findings resemble results for the firms examined by Gebauer, et al., (2012). Both findings would be consistent with Lane, et al., (2006), and Todorova and Durisin (2007), with extensions of the AC model made by Patterson and Ambrosini (2015) and Aribi and Dupouët's (2016) views on the non-linear sequence of AC. Firms either assimilate or transform the new knowledge for internal use and applications to achieve commercial exploitation and Realised AC. This study selected to use Zahra and Georges' AC framework, and specifically the two-stage differentiation of Potential AC and Realised AC. This study does not diminish the four phases of Zahra and Georges' model and may purely indicate assimilation learning processes / behaviours are difficult to identify in highly innovative firms. This could also indicate that they are potentially more important for less innovative firms such as adaptors, imitators, followers or laggards or such similar categories.

As discussed by other research findings, there is a discrepancy between whether AC is a linear process of sequential AC steps (Jansen, et al., 2005; Zahra and George, 2002), versus a non-linear sequence of AC steps (Lane, et al., 2006 and Todorova and Durisin, 2007, Patterson and Ambrosini, 2015 and Aribi and Dupouët, 2016) to achieve its Realised AC. This study confirms that a firm's AC will initially take a pathway following either sequence suggested by Lane, et al., 2006 and Todorova and Durisin, 2007 to source and use an external knowledge source. As such, AC is a full cyclical process that can operate in many different iterative paths between each phase to involve regular feedback loops between Potential and Realised AC, as illustrated in figure 13. When a firm needs additional new knowledge it may take several potential different AC steps prior to reaching full exploitation. Firms, whether they take the assimilation pathway and/or transformation pathway to the exploitation stage; when required to seek further knowledge to achieve full exploitation will return to AC 1 acquisition phase, where it either engages with assimilation or transformation learning until it achieves its Realised AC.

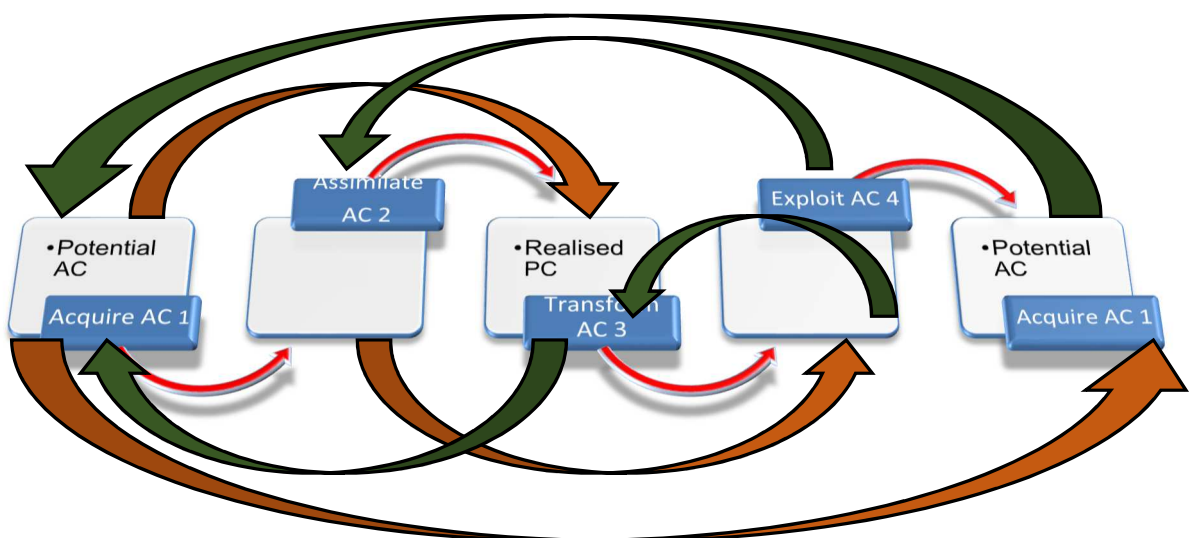


Figure 13: Potential 'iterative' AC Feedback loops

5.6 Absorptive Capacity, Industry-University Collaborations & the NPD Process

This case study represents a range of different industry-university collaboration types that can cover the three broad phases of NPD process. Collaborations undertaken by the firms vary across the four AC stages as described by Zahra and George (2002) and can include a differentiation between the three different stages of the NPD process. For example, the scope of the collaboration itself can be very different according to the phase of the innovation process during which the collaboration takes place. It can go from the exploration of possible new ideas to the final test of existing products (Cooper and Kleinschmidt, 1986). Consequently, collaborating with universities in different phases of the innovation process entails specific challenges for SMEs (Schartinger, et al., 2002), and although the capabilities of an SME are important throughout the entire process, they play different roles in the different phases of the collaboration process itself (Buganza, Colombo, & Paolo, 2014, p. 71). Similarly collaborations undertaken between the firms and the university can reflect different IP protection mechanisms (Miozzo, Desyllas, Lee, & Miles, 2016) known as ‘appropriability regimes’ that are adopted as part of the formal partnering arrangements, which impact the level of openness external knowledge searches and collaboration (Laursen & Salter, 2014); (Colombo, Piva, & Rossi-Lamastra, 2014) and (Criscuolo, Laursen, Reichstein, & Salter, 2018).

The study’s participants have provided personal accounts and experiences as employees involved with industry-university collaborations across three key phases of the NPD process – as summarised in tables 36-39 below. They have responded to a range of unstructured questions based upon their experiences working together on projects discussed in study. These projects often involved taking an analytical knowledge source developed by University researchers that involve a mixture of R&D activities across the following three key NPD phases:

5.6.1 Applied R&D and early Prototype – Laboratory concept phase:

This involves testing and refinement of the science that forms part of the early exportation of new knowledge and technology. It takes the form of an early invention in the form of a new technological process derived from R&D that evolves through to the next phase of ‘proof of concept’ in the form of a model or prototype piece of equipment or machinery.

5.6.2 ‘Proof of concept’ – Prototype developmental phase:

This occurs prior to any major industry investment and potential commercial applications. It involves escalating early laboratory prototypes to larger proven application at industry capacity and standards to achieve cost, quality and volume (quantity) considerations prior to full industrial scale development and commercialisation.

5.6.3 Industrial ‘scaled-up’ – Commercialisation development phase:

This involves a full working factory production scale of the new technology processes for commercial application for the manufacturing to end market users – targeted customers / suppliers; often meeting stringent technical product specifications across a range of matters such as durability, strength, quality of finished surface appearances and treatment, repairability and other savings in production

and ongoing maintenance costs to end users. This NDP process was extrapolated in the following tabulation summary results to create an assessment of AC results for each firm across the three staged NPD process (Buganza, et al., 2014) from evidence discussed in the case study chapter.

Table 36: Firm 1 AC Levels and New Product Development (NPD) Pathways

Firm 1	CE Level 1 and 2 Protective Clothing for Motorcyclists and Sporting Apparel Manufacturing			
NDP Stages	Potential AC – Exploration		Realised AC – Exploitation - Utilise	
	AC1	AC2	AC3	AC4
<p>1. Applied R&D and early Laboratory Prototypes</p> <p>Firms are engaged in applied R&D project with clear outcomes to adopted early exploratory University research into an early prototype technology product and associated technical processes.</p> <ul style="list-style-type: none"> • ST&I knowledge base. • AC 1 and AC 2 learning processes. 	<p>1997 – mid 2000s Exploratory use of Kelvar© protecting lining in early prototypes using textile research into the use of supplied advanced fibre technology with UK university in late 1990s and private testing laboratory in mid to late 2000s.</p> <p>2015 Ongoing R&D collaboration with University post 2015 NPD and incremental refinements with new University laboratory scientific testing equipment, use of expert University research staff embedded in the firm’s business production operations.</p>	<p>2005 onwards Early development of textile research into the use of supplied advanced fibre technology that lead to early university testing in the UK prior to CE Level certification in 2010.</p>		
<p>2. Proof of Concept</p> <p>Prototypes are developed further with more rigorous testing and refinement of product from results of tests to derive final parameters to new product.</p>	<p>2013 ongoing Firm sought University assistance to develop product prototypes for a new market based on technology used in existing product ranges.</p> <p>Firm sought University assistance to develop a product for a new market</p>	<p>2015 ongoing University able to contribute new knowledge to existing product designs by establishing its own testing laboratory with equipment acquired from overseas.</p>	<p>2007-2010 UK University testing and laboratory consultants to achieve firm knowledge.</p> <p>2014-ongoing Firm sought University assistance to develop a product for a new market based on technology used in existing product ranges.</p>	<p>CE Level 1 clothing protective product range released in 2010. Further testing 'n' trial work between the firm and its knitting partners and supplied fibres from DuPont and Diamer developed the firm’s RooMoto™ protective lining textile incorporated from</p>

<ul style="list-style-type: none"> • ST&I plus DU&I 'learning by doing and interacting. • AC 2 and AC 3 learning processes. 	<p>based on technology used in existing product ranges.</p> <p>Developed its own knitting technology with suppliers. Initial testing with UK university developed new knowledge on different knits and weaving patterns to confirm with early clothing protection standards developed in the UK.</p> <p>Later developments with finer and more detail testing with equipment at private laboratory developed the first CE Level 1 product range.</p>		<p>University able to contribute new knowledge to existing product designs by investment in its research program with acquiring both equipment and new research staff in the form of a textile design engineer and personal safety injury prevention researcher linked to NSW Road Safety and Motorcycle Council of NSW (MCC). http://www.abc.net.au/catalyst/stories/4433001.htm</p>	<p>2013 to achieve CE Level 2 protective product range. From 2015-16</p>
<p>3. Industrial Development – Commercialised</p> <p>Product is finalised for large scale manufacturing production runs with firm's knitting machinists and released for initial market launch.</p> <ul style="list-style-type: none"> • DU&I knowledge base. • AC 4 and AC 1 with ongoing feedback loops through to AC2 and AC 3 phases as required. 			<p>Post 2010 2010 – Achieved CE Level 1 protection standard 2013 – Achieved CE Level 2 protection standard</p> <p>2015 Developed new product range for road cyclists that have not been a focus for the company, with little time spent to market the product developed with the University.</p>	<p>Post 2017 - ongoing Further weight reduction achieved – move towards single lining protective garments.</p> <p>Release of new products with weight reduction and increase soft tissue protection https://dragginjeans.net/pages/safety</p>

Table 37: Firm 2 AC Levels and New Product Development (NPD) Pathways

Firm 2 - HQ	Short Polymer Fibres (SPFs) Manufacturing of Surface Textile Treatments			
NPD Stages	Potential AC – Exploration		Realised AC – Exploitation - Utilise	
	AC1	AC2	AC3	AC4
<p>1. Applied R&D and early Laboratory Prototypes</p> <p>Firms are engaged in applied R&D project with clear outcomes to adopted early exploratory University research into an early prototype technology product and associated technical processes.</p> <ul style="list-style-type: none"> ST&I knowledge base. <p>AC 1 and AC 2 learning processes.</p>	<p>2009-2011 After several years of applied R&D Deakin with spin-off firm Cytomatrix (former Deakin University academic researcher) University and an allied firm developed</p> <p>2016-2018 ongoing Deakin with said case study firm combines knowledge to enable the applied R&D to be scaled up to a larger machine to produce industry capacity to launch its first commercial product innovation from this technology platform in 2016 and again in 2018.</p>	<p>2011-2013 University and an allied ‘spin-off’ firm developed an applied technology to process short polymer fibres with an initial synthesising machine developed over this period.</p>		
<p>2. Proof of Concept</p> <p>Prototypes are developed further with more rigorous testing and refinement of product from results of tests to derive final parameters to new product.</p> <ul style="list-style-type: none"> ST&I plus DU&I ‘learning by doing and interacting. <p>AC 2 and AC 3 learning processes.</p>		<p>2014-2015 Firm acquired licensing to University technological and enters into equity agreement with third party to build first large-scale proof of concept prototype fibre synthesising machine for potential industrial scale processing of fibres over this period</p>	<p>2015-2016 Industrialisation scale of technology to produce liquid fibre for synthesising into a useable fabric for applications for surface textile treatments as a protective layer for variety of uses, specifically for comfort, and breathability factors (<i>cooling – maintaining body temperature – assists with perspiration, etc</i>) and wet weather proof.</p>	<p>2016 First product innovation released in mid-2016 followed by second product in early 2018 that reduces pillaging of fibres to reduce textile wear and tear and improve aesthetic and design properties to fabrics.</p>

<p>3. Industrial Development – Commercialised</p> <p>Product is finalised for large scale manufacturing production runs with firm's knitting machinists and released for initial market launch.</p> <ul style="list-style-type: none"> • DU&I knowledge base. <p>AC 4 and AC 1 with ongoing feedback loops through the AC2 and AC 3 phases as required.</p>			<p>2016-2018 ongoing Deakin with said case study firm combines knowledge to enable the applied R&D to be scaled up to a larger machine to produce industry capacity to launch its first commercial product innovation from this technology platform in 2016 and again in 2018.</p>	<p>2018 ongoing Commercial release of second product innovation mid-2018</p>
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Table 38: Firm 3 AC Levels and New Product Development (NPD) Pathways

Firm 3 - CR		Carbon Fibre Wheel Technology		
NDP Stages	Potential AC – Exploration		Realised AC – Exploitation – Utilise	
	AC1	AC2	AC3	AC4
<p>1. Applied R&D and early Laboratory Prototypes</p> <p>Firms are engaged in applied R&D project with clear outcomes to adopted early exploratory University research into an early prototype technology product and associated technical processes.</p> <ul style="list-style-type: none"> • ST&I knowledge base. • AC 1 and AC 2 learning processes. 	<p>2004-2008 Early university research into an automotive carbon fibre wheel technology</p> <p>2015-2020 ARC Research Program contributory funding firm with smaller cluster of SMEs largely based at Deakin University</p>		<p>2010-11 Firm adopts disruptive innovation model as first entry to market and combines other knowledge bases such as aerospace science to design and prototype concepts</p>	
	<p>2016 Early exploration of technology for aerospace and application of carbon fibre ‘wheels’ in other transportation types.</p> <p>2018 New \$15M commercialisation Research Program launched with University & the IM-CRC https://www.carbonnexus.com.au/15m-rd-project-a-good-sign-for-automotive-industry/</p>			






<p>2. Proof of Concept</p> <p>Prototypes are developed further with more rigorous testing and refinement of product from results of tests to derive final parameters to new product.</p> <ul style="list-style-type: none"> • ST&I plus DU&I 'learning by doing and interacting. • AC 2 and AC 3 learning processes. 	<p>2008-11 Early automotive technology development of prototypes for trails in supercar performance cars.</p>	<p>2009-2012 International testing and validation to meet and exceed OEM production requirements. In 2010 the firm adopts disruptive innovation model as first entry to market and combines other knowledge bases such as aerospace science to design and prototype concepts</p>	<p>2013 Onwards Achieving global OEM standards for component supply (TS16949) by early 2013 was a key element of the overall world-class approach to quality and process control.</p>	
<p>3. Industrial Development – Commercialised</p> <p>Product is finalised for large scale manufacturing production runs with firm's knitting machinists and released for initial market launch.</p> <ul style="list-style-type: none"> • DU&I knowledge base. • • AC 4 and AC 1 with ongoing feedback loops through to AC2 and AC 3 phases as required. 			<p>August 2012 Firm launches carbon fibre wheel for Porsche 911</p> <p>2012-2015 Carbon Fibre Wheels design and produced for OEM client markets</p> <p>2017 ongoing R&D, production expansion and diversification into aerospace sector.</p> <p>2018 Commercialisation Research Program launched with University and IM-CRC</p>	<p>2015 US Ford wheels produced for larger mass production of two vehicles produced in Detroit, USA.</p> <p>2018 New European OEM Carbon Revolution is also working with Ferrari on wheels for the 488 Pista,</p>

Table 39: Firm 4 AC Levels and New Product Development (NPD) Pathways

Firm 4 - QS		Carbon Fibre Composite Materials Componentry Parts Manufacturing		
NDP Stages	Potential AC – Exploration		Realised AC – Exploitation – Utilise	
	AC1	AC2	AC3	AC4
<p>1. Applied R&D and early Laboratory Prototypes</p> <p>Firms are engaged in applied R&D project with clear outcomes to adopted early exploratory University research into an early prototype technology product and associated technical processes.</p> <ul style="list-style-type: none"> • ST&I knowledge base • AC 1 and AC 2 learning processes. 	<p>Late 1990s-2005 Firm patents its technology following its unlisted company public status in 2001. Firms forges R&D collaborations with CSIRO, Deakin University and the VACMM in 2004.</p> <p>2007-2018 In-house R&D continues in Munich (Germany) site. Geelong R&D division established at Deakin University in 2015. 2018 Munich operations closed, and transferrable functions moved to Geelong</p>			

<p>2. Proof of Concept</p> <p>Prototypes are developed further with more rigorous testing and refinement of product from results of tests to derive final parameters to new product.</p> <ul style="list-style-type: none"> • ST&I plus DU&I 'learning by doing and interacting • AC 2 and AC 3 learning processes. 	<p>Late 1990s-2005</p> <p>First of many larger OOA curing plants developed to scale and R&D university research centres at Deakin, and other universities in the UK, Germany, Japan and USA.</p>	<p>2005-2008</p> <p>Global research partners with several other universities that forged research connections to Deakin University via the VCCAM – end 2012</p> <p>2008-2013</p> <p>Qualifying projects in conjunction with its US strategic allied partner Vector undertakes process qualification testings to meet sector standards</p>	<p>QPS - Growth Opportunities </p> <p>» Quickstep Production System (QPS) QPS is an advanced lean production system, a complete material to finished part solution</p> <ul style="list-style-type: none"> - Proprietary technology - R&D initiative based in Geelong - Multiple market and part applications <p>» Typical applications include: -</p> <ul style="list-style-type: none"> - Micro-X (portable x-ray device) <ul style="list-style-type: none"> - Carbon fibre chassis using Qure process - Establishes higher volume capability - Global market - Front Fender (automotive) <ul style="list-style-type: none"> - Demonstrates capability for automotive and aerospace - Addresses rate needed and part complexity - For European luxury automotive manufacturer  	
<p>3. Industrial Development – Commercialised</p> <p>Product is finalised for large scale manufacturing production runs with firm's knitting machinists and released for initial market launch.</p> <ul style="list-style-type: none"> • DU&I knowledge base • AC 4 and AC 1 with ongoing feedback loops through to AC2 and AC 3 phases as required. 		<p>2009-2013</p> <p>RTS achieves OEM recognition in joint research project. Sale and licensing of technology to two external global customers.</p>	<p>2014-onwards</p> <p>Technology exploitation of firm's appropriated knowledge through product development demonstrator projects with European/US automotive OEMs.</p> <p>Ongoing external partnerships including the recently announced that we have signed a Manufacturing Partnership Agreement with ATR Group, a leading Italian company that designs, prototypes and manufactures structural parts and components in advanced composite materials.</p>	<p>2016</p> <p>Completed OEM contract with Ford US partially use of firm's technology.</p>  <p>2017-18</p> <p>Completed use of QPS technology with Micro-X-ray carbon fibre exterior body shell.</p>

The three phases of the NPD process outline above mirrors similar processes identified by Buganza, et al. (2014, p.72). Buganza, et al. (2014) identified several capabilities developed by SMEs as part of the NPD process. From this study, it appears the narrower the collaboration between industry and universities in the NDP process, the fewer collaboration types a SME are likely to undertake with a university. The shallower a firm engages with the NPD process across the different industry-university collaboration types may reduce opportunities for firms to developed capabilities to sense, learn and integrate its AC capabilities. As suggested by Darawong (2015), frequent communication amongst NPD team members can effectively enhance the ability of absorbing and using both internal and external knowledge. In addition, a firm's internal capabilities with higher learning, integrating and coordinating capabilities will enhance project efficiency (Darawong, 2018).

Previous research suggests where a firm can transition (*where relevant to a firm's product and technology application*) through the entire NPD process with a university they will develop and/or have a high AC, particularly with technology management and project management capabilities. The extent to which a firm collaborates with the university varies with a firm's AC and the depth and extent to which it engages the research capacity of the University during a firm's NPD process. Very few industry-university collaborations extend across the full NPD process (Buganza, et al., 2014, pp. 80-81). Those firms that are able to collaborate with universities across the full spectrum of the NPD process can achieve their Realised AC sooner, which from this case study appears to reflect the experiences of the first two smaller SMEs. It appears the narrower the collaboration between industry and universities in the NDP process fewer collaboration types a SME are likely to undertake with a university. When firms collaborate with universities across the entire NPD a firm's AC transcends all phases of AC. It appears greater a firm is aligned with the university's research program through the entire NPD process, greater is a firm's AC is. These firms also have a greater ability to precede through to commercial exploitation, reaching the market successfully with its product innovations faster.

Similarly, collaborations undertaken between firms and universities also vary with the type of innovation performance management mechanisms which can reflect the various IP protection mechanisms or 'appropriability regimes' adopted as part of the formalities of a formal collaboration arrangement. Attention is drawn to how different forms of openness can be connected to different levels of IP protection. Miozzo, et al., (2016) defined up to eleven mechanisms and grouped them under three types of appropriability orientations either under formal, strategic and contractual.

- **A formal orientation emphasises** the significance of patents, copyrights, trademarks and design rights to capture value from innovation by firms.
- **A contractual orientation highlights** the significance of confidentiality agreements, employment contracts, and secrecy to capture value from innovation.
- **A strategic orientation stresses** the importance of lead-time advantages, complexity of the service or service process, and complementary service development and delivery capabilities to capture value from innovation.

Laursen and Salter (2014, p.876) highlights the positive and negative aspects of appropriability for open innovation. They found evidence that an overly strong emphasis on appropriability can be associated with reduced efforts to acquire knowledge from diverse external partners in formal collaborations for innovation. In addition, they draw attention to how different forms of 'open-ness' might be connected to knowledge appropriability concerns. We found that the negative side of appropriability (a concave rather than a linear relationship) and its link to openness is greater for formal collaboration than for external search breadth. This supports the hypothesis that the "scaring off" effect is stronger for direct collaboration than for external search which involves less two-way interaction. They uncover a 'paradox of formal appropriability mechanisms' in the case of knowledge-intensive business services (KIBS) firms.

Despite evidence that KIBS firms do not typically consider formal appropriability mechanisms, such as patents, to be central mechanisms for capturing value from innovation, it is shown that they are nevertheless important for their innovation collaboration. Drawing on an original survey of publicly-traded UK and US KIBS firms, they identified a significant positive association between the importance of innovation collaboration and the importance of formal appropriability mechanisms. We find that the importance of innovation collaboration with clients goes hand-in-hand with the importance of formal appropriability mechanisms, although a negative relation appears when firms assign very high importance to formal appropriability mechanisms. Thus, modest levels of emphasis on formal appropriability mechanisms may prevent conflicts over ownership of jointly developed knowledge assets and knowledge leakages, while also avoiding the possibly negative effects of overly strict controls by legal departments on innovation collaboration.

In this study, product innovations are the net outcome of the AC process – that achieves Realised AC in the form of commercial gain in the form of either a new product manufactured in the form of a finished good or intermediary component part. The industry collaborations formed with university input have resulted in successful product innovation outcomes by the firm – this is predominantly viewed as a direct result of the firm's existing patented and or developed/acquired new knowledge. Some firms whilst pursuing their AC undertake various exploratory activities – whereby new knowledge is processed internally to expand its technology development in the pursuit of customer requirements – that also gain technology accreditation – qualification of the firm's technology as in the case of those firms that work with OEM customers such as larger two SMEs in this study.

In the exploratory phases firms sourcing new knowledge from the University occurs in less formal ways – which pertains to the nature of knowledge specially the tacit (implicit) aspect to it – hence early face to face regularly contact between external partners is important, which can be assisted by physical proximity of collaborative partners. This informal collaboration and partnering is common at the early applied research and development of concept phase of new product developments prior scaling up in the remaining two phases of the NDP process - namely to early prototype development and final industrial commercial development of product. This often entails a firm's internal innovation

capabilities – in particular its intra-organisational capacity to manage the nature of knowledge flows between a firm and its external partners. The consequent innovation-related benefits may differ according to the interaction channel, the firm's R&D partner and the project phase. Firms' external knowledge R&D partners complement or substitute each other, in the latter case mostly because academic researchers may be time constrained and less available to engage in technology-development projects. Firms choose universities as R&D collaboration partners in cases of multi-purpose problems and learning-focused projects in areas involving new science and producing long-term benefits, such as strengthening their absorptive capacities and radical innovation; the motivation is that these projects are more likely not to be aborted prematurely (Maietta, 2015, p. 1344).

5.7 Innovation Capabilities

Buganza, et al., (2014, p.72) frame their discussion of SMEs innovation capabilities around the benefits of collaborating with universities derived from a firm's dynamic capabilities (Teece, et al., 1997) and an adequate level of AC (Cohen and Levinthal, 1989, 1990). Strengthening in-house R&D capacity, or AC (Cohen and Levinthal, 1989) is vital to engage in industry-university collaborations effectively (Motohashi, 2005). Prior research has shown that collaborations with universities can be beneficial in all three NPD phases (Lee, 2000; Santoro and Chakrabarti, 2002) but research has yet to focus on how SMEs could establish collaborations with universities during the different phases. Buganza, et al., (2014) study sought to understand more about how SMEs could improve their ability to manage collaborations with universities, with a specific focus on the development of new products, since this specific type of collaboration is the most common among SMEs (Motohashi, 2005).

The results of Motohashi's study was based on an extensive national industry-university collaboration survey and found that large enterprises primarily use such collaborations for joint research projects to strengthen their in-house technological capabilities and achieving long-term benefits, while a higher percentage of SMEs seek to acquire technology through technical consulting and joint R&D technologies closer to the final product stage. Large firms, while using the same joint R&D collaborations, place greater weight on basic and fundamental types of knowledge that can be expected to lead to long-term innovations, by seeking to upgrade their own research capabilities. One factor leading to this result may be that the strategic timetable for industry-university collaborations differs between large enterprises, with relatively large R&D resources such as in-house research centres, and smaller firms, which lack such resources.

Similarly, Santoro and Chakrabarti (2002) showed that SMEs usually prefer to manage projects with universities using arrangements specifically designed to address immediate problems, and place greater emphasis on evaluating the development of new products and technologies such as contract research and faculty consulting. Organisational routines also play an important role in the management of these collaborations. Santoro and Chakrabarti (1999) point out that the organisational structure, planning/controlling processes and co-ordination systems have a deep impact on the outcome of collaborations. Similarly, the presence of both university and firm

champions (individuals) can play an important role in establishing fruitful collaborations (Santoro and Chakrabarti, 2002). Champions promote new product ideas (Schon, 1963) and create a link between people and organisations (Hauschildt, 1999). Moreover, university-industry collaborations are projects, and hence the maturity of project management practices within a firm can influence the results of the collaborative NPD process (Buganza, et al., 2014, p.72).

Buganza, et al. (2014, p.70 and p.73) elaborates on their evidence to highlight the importance of two distinctive broad capability types to manage complex industry-university collaborations successfully

- technology management capability; and
- project management capability.

The former is related to the SMEs ability to identify relevant technologies and integrate university knowledge within their processes, while the latter refers to the SME's ability to adequately manage innovation projects in terms of quality, cost and time. The literature has identified a set of factors that can lead to project failure, such as the absence of a project manager and wrong resource allocation or task schedules (Pinto and Slevin, 1988; Milosevic and Patanakul, 2005). Firms on one hand must be able to manage collaboration projects with universities and develop project management capabilities. The importance of these capabilities is also confirmed in this case study.

Buganza, et al. (2014) investigated the relationship between these capabilities and the firms' ability to manage complex collaborations (e.g. during the research phase) and it appears that SMEs perform differently on these capabilities. SMEs that collaborated with universities during the entire NPD process show a high level of both technology management and project management capabilities. Other firms are highly capable in only one area and finally, other firms, performed poorly in both areas. All the SMEs that collaborate during the testing and development phase developed at least one of the two main capabilities considered. Finally, half of the firms that engaged in testing activities do not present significant levels of either technology management or project management capabilities. Based on this these two capability types are intimately related to the phases of the NPD process in which these collaborations take place and reflect from the progressive behavioural model of SME-university collaboration. A firm's innovation capabilities can be therefore being studied across these two broad categories particularly when it comes to its AC (internal or external capabilities), type of industry-university collaboration and the relationship to the NDP. A summary is provided of such an assessment below in tables 40 and 41.

Table 40: Summary of SMEs NPD Innovation Capabilities

Firm 1
Technology Management Capability
Medium
Early technology management of the firm's Potential AC evolved through selective use of technology gatekeepers and scouts. The firm's technology capability managed by initial university scientific knowledge and testing. This evolved further with additional external technological assistance to achieve initial Realised AC in 2010 with unique product outcome and consolidated with further advancements of its technology application in 2013 onwards.
Project Management Capability
Medium-High
The firm's strong strategic direction by its owner and allied internal staff lead to a very hands-on personal approach. The firm's technology develops through social relationships and networks developed by the owner. Projects evolved through use of external assistance as discussed. The owner has individually driven and overseen new technology management with initial contact with Deakin University in 2013. Forging an enterprise connect NPD outcome with the University in 2015. Ongoing refinement of the firm's technology capabilities built up with consolidating its market position and relationship with University researchers.
Firm 2
Technology Management Capability
High
Early technology management of the firm's Potential AC evolved with a technology discovery at the University. This discovery forged problem-solving solutions to the firm's own technology needs. Acquiring IP from the initial University R&D and spin off company lead to the firm scale up technological processes to manufacturing short polymer fibres to the market place in 2016 and 2018 with a second innovation product.
Project Management Capability
High
The lead by an executive research manager with a personal approach with allied University R&D staff identifies complementary knowledge at the University. The firm's technology develops through strong cognitive and social relationships forged by the firm and University research. A research and education agreement with the University and other IP arrangements lead to firms first industry scale machine built in late 2015. Ongoing refinement of the firm's technology capabilities with the University results in product innovations launched in 2016 and 2018. The firm's technology continues to be advanced with numerous applications of its patented platform.
Firm 3
Technology Management Capability
High
The firm's single piece wheel architecture is produced using a patented manufacturing process achieved major 2012 win with the firm's first OEM contract. This success continues and now technology management extends to use of the firm's knowledge and technology capabilities to early Potential AC in different industry sectors.
Project Management Capability
Medium-High
Strong consistent small group of technology co-inventors provides a consolidated cognitive logic that leverages from strengths of core team and strategically selected skilled staff lead the firm's Realised AC in 2012 with its first OEM contract and subsequent contracts. The firm's technology evolves to new OEM requirements and expansion into its exploratory Potential AC in other carbon fibre wheel types for different industry sectors such as aerospace.

Firm 4
Technology Management Capability
Medium-High
Strong exploratory advances with its patented technology to 2012-13 with a number of smaller successful product developments and demonstration projects. Full commercialisation of technology capabilities with further R&D advancements.
Project Management Capability
Medium
Original co-inventors and management develop numerous advances of the technology that has waned since 2012-13 due to changes to management and R&D staff. A diversified cognitive logic with a top-heavy executive management team combined with organisational memory loss has yet to see the firm achieve its Realised AC with its carbon fibre technology capabilities.

Table 41: Summary of NDP Phases and Innovation Capabilities

Firm	SMEs Innovation Capability				
	Technology Management	Project Management	NPD Process - Phases Taken		
	Capability Level	Capability Level	Applied R&D	Proof Concept 'Testing & Validation'	Industrial Commercial
1	Medium	Medium-High	√	√	√
2	High	High	—	√	√
3	High	Medium-High	—	√	—
4	Medium-High	Medium	—	√	√
√	Evidence				
—	No evidence				

5.8 Industry-University Collaborations, AC and the NDP process

A firm's AC appears greater when it has realised the potential of the new knowledge acquired from the university in terms of production innovation outcomes. Furthermore, the firms' AC appears to be enhanced where it involves one or more of the four types of industry-university collaboration projects identified by Perkmann and Walsh (2009, p. 1046) as shown below. In this instance, a firm has proceeded through the three stages of the NPD process with the university and involves at least problem solving and technology development types of collaboration with the University.

1. **Problem solving** - providing advice regarding technical problems arising within a firm's R&D, manufacturing or other operations.

2. **Technology development** - developing design specifications or prototypes for new or improved products or processes.
3. **Ideas testing** - exploring a high-risk concept on behalf of a firm – outside the firm’s mainstream activities.
4. **Knowledge generation** - carrying out research on topics of broad interest to a firm.

Perkmann and Walsh (2009, p. 1046) highlight the implicit relationship between the learning types or goal, with its function, the type of collaborative interaction with a university, the nature of interactions and level of joint activity – as shown in table 42 below. This was extrapolated in the following tabulation results drawn from the case study chapter.

Table 42: Relationship with Collaboration Types, Learning and Joint Activity

Type - Goal	Description	Meetings	Equipment materials exchange &	Joint Activity
Problem Solving	Providing advice regarding technical problems arising within a firm’s R&D, manufacturing or other operations.	Very frequent – information exchange and decision making	Implicit in nature of project	Always
Technology Development	Developing design specifications or prototypes for new or improved products or processes.	Frequent – information exchange and decision making	Implicit in nature of project	Always
Ideas Testing	Exploring a high-risk concept on behalf of a firm – outside the firm’s mainstream activities.	Relatively rare – information exchange	Sometimes	Rare
Knowledge generation	Carrying out research on topics of broad interest to a firm.	Relatively rare – information exchange	Sometimes	Very Rare

An assessment of AC results for each firm across the three staged NPD process (Buganza, et al., 2014) combined with different industry-university collaboration types (Perkmann and Walsh, 2009). An assessment of each of the firms’ AC when as it pertains to the NPD process and the type of industry-university collaboration has been made in table 43 below.

Table 43: Assessment of SMEs Collaboration Types and the NPD Process

SMEs AC, NPD and Collaboration Types							
Project types in industry-university-collaboration	NPD Process - Phases Taken			Evidence of Collaboration Found			
	Applied R&D	Proof Concept 'Testing & Validation'	Industrial Commercial	Firm 1	Firm 2	Firm 3	Firm 4
Perkmann and Walsh (2009)							
1. Problem Solving	≠	≠	√	√	√	√	√
2. Technology Development	≠	√	—	√	√	—	—
3. Ideas Testing	√	√	—	√	√	—	—
4. Knowledge Generation	√	√	—	√	√	√	√
Notes							
—	Complementary NPD collaboration work – No evidence, early development and/or yet to be completed work.						
≠	Non-complementary NPD collaboration work – Industry and University research work not mutually exclusive (insufficient mutual interests and motivations)						
√	Complementary NPD collaboration work – Industry and University research work is mutually exclusive (sufficient mutual interests and motivations)						
Problem Solving	The first type of project focuses upon when firms approached academics to assist them with specific problems encountered in their R&D, engineering or manufacturing operations. Firms sought specialist advice provided by academics on particular problems, or involvement in the actual problem-solving activity. The projects involved products, processes or concepts that were either close to market or already on the market, or parts of firms' machinery and equipment. Therefore, the projects were characterized by low degree of technological or scientific uncertainty as the requirements were strictly defined by the problems to be resolved.						
Technology Development	A second project type focused more directly on improving or developing specific technologies relevant to commercial users. Often such projects resembled conventional, formally established academic research projects although substantially they pursued proprietary technology development. These projects dealt with concepts, products or processes, which, compared to problem solving projects, were a step removed from "market readiness". They were afflicted by relatively higher degrees of uncertainty as only general requirements were known, while the actual problems to be resolved were not tightly specified ex ante.						
Ideas Testing	Ideas testing type of projects was inspired by the desire to investigate potentially commercially interesting ideas. These projects sometimes built on concepts and technologies developed by academics which they "sold" to firms to pursue tentative exploration of their application potential. In other cases, specific ideas had emerged within firms' R&D or manufacturing units and the firms had approached the academics to explore these ideas because they were seen as having the required expertise.						
Knowledge Generation	The last project type consisted essentially of academic research projects with industry participation. These projects in most cases were initiated by academic researchers. The objectives of these projects tended to be informed by the challenges arising at the frontier of academic research. In all cases analysed, projects of this type were completely or partially supported by public research funding. In general, the industry partners were approached at the stage when project proposals were already well defined. They often agreed to take part by contributing "in kind," i.e. by committing management time, materials, and occasionally access to prototypes and their laboratories.						

There are two overriding barriers to collaboration between industry and universities, and this relates to the nature and type of collaboration projects identified by Perkmann and Walsh (2009, p. 1046) (*problem solving, technology development, ideas testing, and knowledge generation – ‘academic basic’*). The two barriers pertain to the extent:

- to which the collaboration aligns with industry and university perspectives and the level of new (novel) knowledge being created/and or obtained, and
- of time and resources that a university will spend on activities that do not directly produce academic output.

Both barriers can reduce the traditional motivations of universities to engage with industry. The higher novelty value or more radical nature of the R&D collaboration outcomes can impose greater ‘secrecy problems’ with potential IP restrictions. This can limit or delay potential academic outcomes in terms of publications and increase formalities of further research work. Secondly the less novel/radical or more ‘applied’ the R&D collaborations are may discourage interest from academic researchers due to lack of complementarity between industry-related activities and open science, and less potential opportunities for academic research publications (Perkmann and Walsh, 2009, p.1037).

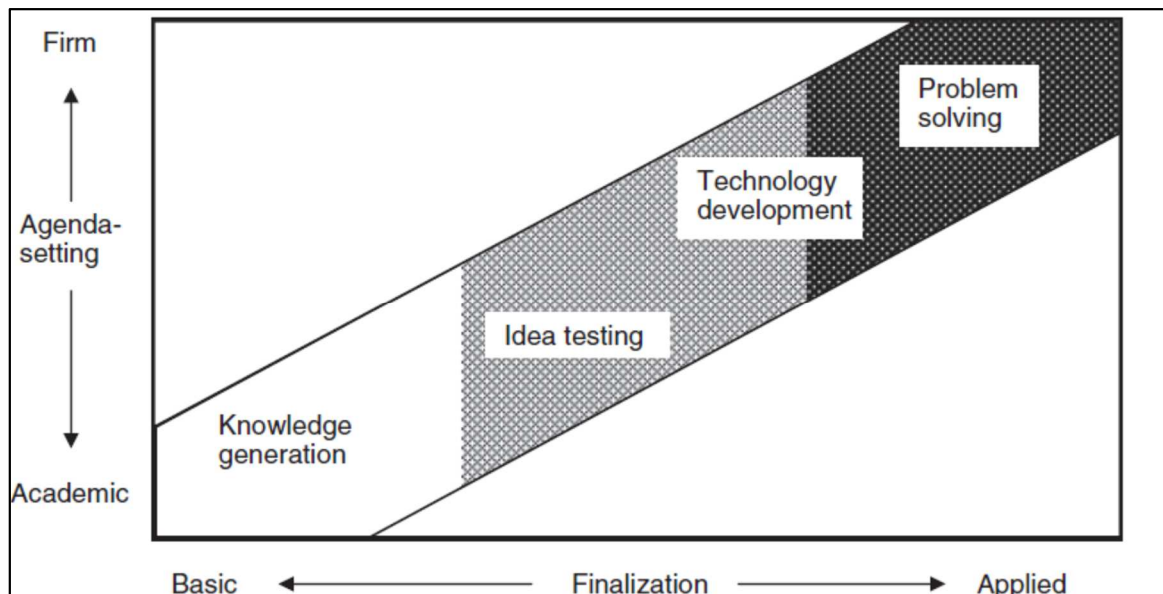


Figure 14: Industry-University Collaboration Types and Motivation Agendas

The above chart (Perkmann and Walsh, 2009, pp.1047) indicates the type of university–industry collaborative projects is likely to fall. Projects that are more applied are likely to be shaped by industrial partners’ agenda, while those that are more basic tend to be shaped by academics’ agendas. The chart above can also indicate that when industry initiates collaborations with a university – it tends to be for a clearer outcome and shorter-term industry need – they are less interested in collaborations involving long-term ‘blue-sky’ outcomes – particularly if funding is being sought from industry to participate in the process. Perkmann and Walsh’s (2009) analysis suggests that academics face a potential dilemma when they collaborate with industry; while more ‘basic projects’ are more likely to generate academic output, they also offer fewer cross-boundary learning opportunities. As such:

- projects are often led and carried out by academics and address topics less directly relevant to industry, and
- partners tend to be less involved and hence interactive learning effects are reduced.

In contrast, although the attractiveness of applied projects is hampered by secrecy and complementarity problems, they offer more learning opportunities during via highly interdependent interaction with industry. Many observers have emphasised commercialisation as the primary rationale informing academics' involvement with industry. The claim is that the role of academics is gradually shifting. Rather than concentrating on "blue-skies" research, academics are seen to be increasingly eager to bridge the worlds of science and technology entrepreneurially, notably by commercialising technologies emerging from their research (Clark, 1998; Etzkowitz, 2003; Shane, 2004). These types differ with respect to their level of application, such as their proximity to market. While problem-solving projects addressed issues relating to products, processes or services that are close to market, at the other end of the scale, knowledge generation projects make only very generic reference to market-ready products or services.

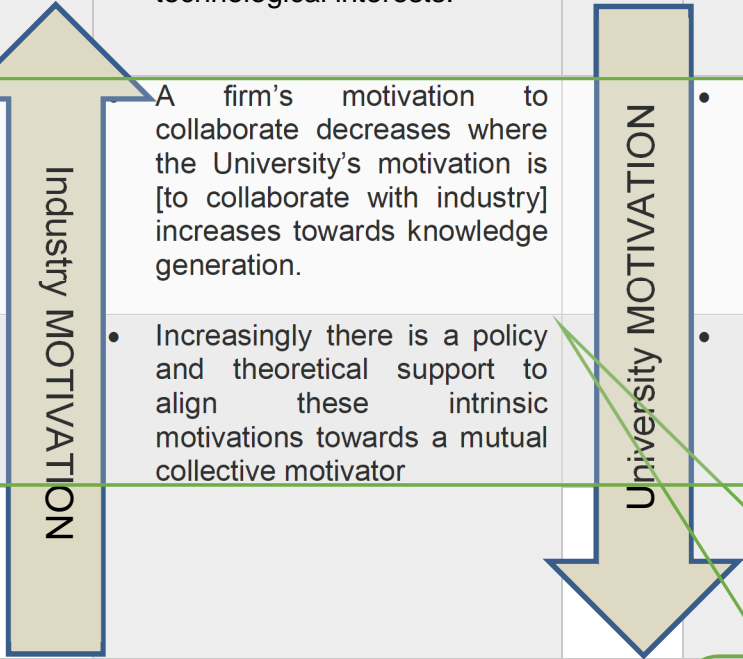
Industry collaboration has differing effects on the production of academic knowledge, depending on the objectives pursued. While basic projects lead to immediate scientific output, more applied projects involve higher degrees of interactivity which in turn generate learning opportunities. Universities can capitalise on these industry collaboration opportunities for the benefit of scientific production particularly if:

- their discipline is associated with the sciences of the artificial;
- they are highly research-driven; and
- they have a portfolio of different types of relationships with industry (Perkmann and Walsh (2009, p.1056).

In many applied projects Perkmann and Walsh (2009, p.1057) studied, the locus of entrepreneurial action, *e.g. opportunity recognition*, resided in the firms that recruited academics into project solving or technology development. An overemphasis on turning academics (and universities) into economic entrepreneurs seems therefore misplaced, *particularly as far more academics engage in collaboration with industry than in spin-off companies or patenting* (D'Este and Patel, 2007). Equally, firms consider these interactions as more valuable than IP transfer (Cohen et al., 2002). Instead of making scientific research directly relevant to industrial applications, policy should promote the capability of academic researchers as skilled experts and consultants rather than entrepreneurs. In other words, 'universities should leverage talent not technology' (Florida, 1999). This would facilitate fruitful interaction between the worlds of science and industry while preserving and building their respective strengths.

Table 44: Industry and Universities Collaboration Types, Description and Motivators

Collaboration Types	Description	Industry	University
1. Problem solving	<ul style="list-style-type: none"> Providing advice regarding technical problems arising within a firm's R&D, manufacturing or other operations. 	<ul style="list-style-type: none"> The type of collaboration varies to the degree of impact to a firm's current and future knowledge and technological interests. 	<ul style="list-style-type: none"> The type of collaboration varies to the degree of impact to a university's research interests area and capabilities.
2. Technology development	<ul style="list-style-type: none"> Developing design specifications or prototypes for new or improved products or processes. 	<p>A firm's motivation to collaborate decreases where the University's motivation is [to collaborate with industry] increases towards knowledge generation.</p>	<ul style="list-style-type: none"> The type of collaboration with industry will increase when a university can generate new ideas and knowledge, traditionally viewed in terms of academic publishing and new knowledge generations.
3. Ideas testing	<ul style="list-style-type: none"> Exploring a high-risk concept on behalf of a firm – outside the firm's mainstream activities. 	<ul style="list-style-type: none"> Increasingly there is a policy and theoretical support to align these intrinsic motivations towards a mutual collective motivator 	<ul style="list-style-type: none"> Increasingly there is a policy and theoretical support to align these intrinsic motivations towards a mutual collective motivator
4. Knowledge generation	<ul style="list-style-type: none"> Carrying out research on topics of broad interest to a firm. 		



Increasingly there needs to be a shift to the middle between the intrinsic knowledge and R&D motivations of industry and universities.

Table 45: Firms AC Innovation Capabilities Assessment and NDP Phases Taken

SME	SMEs Innovation Capability						
	Technology Management		Project Management		NPD Process - Phases Taken		
	Capability Level	Brief Description	Capability Level	Brief Description	Applied R&D	Proof Concept 'Testing & Validation'	Industrial Commercial
1	Medium	Early technology management of the firm's Potential AC evolved through selective use of technology gatekeepers and scouts. The firm's technology capability managed by initial university scientific knowledge and testing. This evolved further with additional external technological assistance to achieve initial Realised AC in 2010 with unique product outcome and consolidated with further advancements of its technology application in 2013 onwards.	Medium-High	The firm's strong strategic direction by its owner and allied internal staff lead to a very hands-on personal approach. The firm's technology develops through social relationships and networks developed by the owner. Projects evolved through use of external assistance as discussed. The owner has individually driven and overseen new technology management with initial contact with Deakin University in 2013. Forging an enterprise connect NPD outcome with the University in 2015. Ongoing refinement of the firm's technology capabilities built up with consolidating its market position, and relationship with University researchers.	√	√	√
2	High	Early technology management of the firm's Potential AC evolved with a technology discovery at the University. This discovery forged problem-solving solutions to the firm's own technology needs. Acquiring IP from the	High	The lead by an executive research manager with a personal approach with allied University R&D staff identifies complementary knowledge at the University. The firm's technology develops through strong cognitive and social relationships forged by the firm	—	√	√

		initial University R&D and spin off company lead to the firm scale up technological processes to manufacturing short polymer fibres to the market place in 2016 and 2018 with a second innovation product.		and University research. A research and education agreement with the University and other IP arrangements lead to firms first industry scale machine built in late 2015. Ongoing refinement of the firm's technology capabilities with the University results in product innovations launched in 2016 and 2018. The firm's technology continues to be advanced with numerous applications of its patented platform.			
3	High	The firm's single piece wheel architecture is produced using a patented manufacturing process achieved major 2012 win with the firm's first OEM contract. This success continues and now technology management extends to use of the firm's knowledge and technology capabilities to early Potential AC in different industry sectors.	Medium-High	Strong consistent small group of technology co-inventors provides a consolidated cognitive logic that leverages from strengths of core team and strategically selected skilled staff led the firm's Realised AC in 2012 with its first OEM contract and subsequent contracts. The firm's technology evolves to new OEM requirements and expansion into its exploratory Potential AC in other carbon fibre wheel types for different industry sectors such as aerospace.	—	√	—
4	Medium-High	Strong exploratory advances with its patented technology to 2012-13 with a number of smaller successful product developments and demonstration projects. Full commercialisation of	Medium	Original co-inventors and management develop numerous advances of the technology that has waned since 2012-13 due to changes to management and R&D staff. A diversified cognitive logic with a top-heavy executive		√	√

		technology capabilities with further R&D advancements.		management team combined with organisational memory loss has yet to see the firm achieve its Realised AC with its carbon fibre technology capabilities.			
√	Evidence						
—	No evidence						

5.9 Absorptive Capacity (AC) Model Framework & NPD Process

A firm's AC is a framework by which businesses such as SMEs can obtain a competitive advantage and sustain that through the lifecycle of a product by a continual renewal of its knowledge stock. When a firm seeks to acquire new knowledge to inform technological improvements to refine or create product innovations it must engage in a wide range of innovation activities. Across these innovation activities a firm's AC can be informed by a number of organisational antecedents. These were discussed pursuant to literature (Volderba, et al., 2010) and more recent contributors. This study identified relevant antecedents across the four learning processes of the AC identified by Zahra and George (2002). Furthermore, a firm's AC was analysed and presented as a process by which a business collaborates and engages with a university through phases of a typical new product development (NPD) process. The extent of a firm's collaborations with the University across the NPD process can parallel a firm's AC across the two main phases of Potential and Realised AC.

The study's evidence suggests a firm's AC appears greater when it has realised the potential of the new knowledge acquired from the university in terms of production innovation outcomes. Specifically, a firm has proceeded through the three stages of the NPD process with the university and involves at least problem solving and technology development types of collaboration with the University. This study reveals a pattern where a firm's AC develops as the firm proceeds through the NPD process in combination with engaging in one or more collaboration types undertaken with the University. Moreover, when a firm's AC trajectory extends across the three broad identified phases of the NPD process, it engages in deeper collaboration arrangements with the University. This occurs with the collaboration types align with both the core business technology interests and the University's research outlook.

A firm's product innovation management and performance are achieved through the NPD process in the form of either a finished or partial (intermediary) component product used in one of its customer's finished products. The success of these outcomes occurs or can be achieved due to different antecedents associated with the AC concept. New technologies generally have a maximum lifecycle of approximately 20 years before becoming relatively superseded by imitators or newer technologies by incumbent or rival new firms, as such the time spent (efficiency ratio) to exploit its technology advantage is critical. The timeline from when a firm's AC develops and grows to reach full realisation of its technology is critical to its innovation performance/outcomes.

The duration of the pathway for a firm to proceed from **Potential AC** to achieve product innovation performance and the full commercialisation of their technology are different from one firm to another. A firm will have a greater chance (likelihood) to achieve its **Realised AC** when it engages in a range of collaboration types across the NPD process, in particularly if they collaborate closely with the University beyond that of applied research stage. These patterns can be attributed to other considerations such as level of novelty of innovation, the ability to work with potential customers and other businesses (upstream or downstream to create added value – such as OEM customers) to

adopt the firm's technology; the firm's level of entry (first entry / early movers, latent movers, imitators and laggards); and the extent to which they collaborate with an external knowledge partner, such as a university, through the NPD process. Where a firm and the University transcend its collaboration across all NPD phases it achieves Realised AC and releases products / launches new products to its market. This is the case with the first two smaller SMEs, their products were less disruptive, they maintained a high novelty (radical) value; and were incremental innovations in both firms' pipeline of innovative products. These are considered innovations new to both firms' markets.

A cautionary note to these conclusions relates to the radical or disruptive nature of the technology base developed, which to some extent has been reliant on the knowledge depth of the University's research base and associated programs. Where a university has developed a depth of knowledge (research integrity and reputation) in a technology discipline can be a factor that enhances the transferability of new knowledge to industry. Where firms develop their own technology base (as in the case of the last two SMEs) and this is embedded internally to their organisation (*secured with IP protection and the like*) the assimilation of this knowledge and its advancement with a university can be delayed. As such, it could be said, if the technology has been developed from inception and developed internally to an organisation, removed from university involvement; the extent to which a university can collaborate with the firm's technology is limited to receptivity issues of the receiver.

Similarly, this is an issue for universities when exchanging knowledge to industry, when industry is not as familiar and invested in the university research programs and priorities. Firms that develop their AC become good collaborators with universities, particularly across both technological and project management capabilities; and the research would suggest those that do it better will cooperate with the university through all the NPD process. It would seem those firms that rely on universities for only one or two of the three phases of the NPD process, are less invested / or aligned with the university's research strengths. The alternative view is that the university has yet to penetrate or develop 'deeper connections' with a firm's overall knowledge and technology base (as oppose to be involved in just a partial component). Either scenario may represent lack of both technological and project management capabilities from both sides.

When the mutual interests of the firm (representing industry) and the university are less developed collaborations can be limited to the lower order types such as *facility sharing, basic testing or qualification or problem shooting solutions to ancillary aspects of the firm's technology*. Whilst this is important for the firm – it is of less interest to the university – due to limited academic new knowledge that it can generate – which has been a traditional university research function – such as achievement of publications in highly cited journals. Patented new technologies generally have a maximum lifespan anywhere between 10-20 years (Byun, Sung, & Park, 2018), depending on the industry sector, before becoming relatively superseded by imitators or newer technologies by incumbent or rival new firms, as such the time spent (efficiency ratio) to exploit its technology advantage is critical.

As discussed, those firms that spend more time in the transformation phase or indicate that is where much of their activity is spent – slower are the exploitation outcomes. The assimilation and transformation phases play different roles across the firms; those firms expending less activity in the assimilate phase can use existing business capabilities built up over time, without a need for transformation, prior to exploitation. Where firms need to transform their internal process and routines before exploiting their technology advantage and knowledge ‘know-how’ greater time is taken to reach exploitative success. As such greater a firm’s ability to proceed through the AC phases in the traditional linear sequence to achieve realisation of its technology to the market for commercial gain sooner it can undertake continuous learning processes and internal routines to expedite quicker and continuously flows of product innovations – whilst taking different iterative steps between each AC phase.

For example, in the case of the first two firms their technology base is relatively stable and can proceed with a potential pipeline of product innovations subject to marketing and customer applications, less restricted by timeframes associated with technical qualifications and other product specifications by its potential customers, such as global OEMs. In the case of the first two firms the firms have realised their AC quicker due to compatibility match, or as implied by Perkmann and Walsh (2009, p.1037) avoids the ‘complementarity problem’, with the university’s knowledge base. These firms have advanced with commercial realisation of new knowledge sourced from the university over a shorter timeframe (2013-16) that continues with incremental process improvements today. Both of the firms’ technology platforms / knowledge base has benefited from a longer-term research programs developed across a suite of projects in the fibre/textile processing and synthesising of short fibres and the like that can be traced back to late 2000s at Deakin University.

In the case of firm 1 and 2 the firms have realised their AC quicker due to compatibility match with the university’s knowledge base – research interests that have been developed as part of a longer-term research program across a suite of projects in the fibre/textile processing and synthesising of short fibres and the like that can be traced back to late 2000s. In the case of firm 3 and 4 the firms Realised AC has taken longer to achieve despite their connections to the university’s research programs being developed much earlier than for firms 1 and 2. Firm 3 technology developed from as early as between 2004-06 with a combine team effort of PhD students/graduates and staff from Deakin.

This emerged into larger operations to produce the first single to OEM manufacturer in 2012 and ultimately setting up large scale manufacturing facility in 2015 at the University. Firm 4 has the longest gestation period stemming from its initially idea in the late part of 1990s to patented technology in 2005 and continuous refinement to produce faster curing and higher A grade quality finished for carbon fibre and composite material parts lead to its other technology in 2013. These technologies are combined to produce a manufacturing capacity for large volume parts with its print to finish process.

The assimilation of new knowledge sees the firms evolve by its AC to adapt prior product and technology knowledge with new internal routines to design new product/new product innovations. In the case of the first SME this was seen in the road cyclist protective clothing products, which have

been developed for the market. This involved understand the use of different fibres – *namely...to provide cyclists comfort – in particularly cooling properties to deal with perspiration (sweat) with a fabric that provides for quick absorption and drying properties.* The abrasive protective features built into the cyclist garments protects specific parts of the body cyclists are vulnerable in an accident, namely knees, elbows and shoulders. This firm is in later stages of an undisclosed NPD, where the University has undertaken phase two and three of the NDP process to include pilot testing of several prototype clothing products.

The Realised AC of the two larger firms has taken longer to achieve despite having developed connections to the University's research programs earlier than for the first two firms. The third firm's technology developed from between 2004-06 with a combine team effort of PhD students/graduates and Staff from Deakin, with a first prototype of its product available for limited uses in 2008 and wider global commercial applications of its product with an OEM manufacturer in 2012. This culminated with establishing a large-scale manufacturing facility in 2015 at the University. As this firm seeks to expand its disruptive technology to other wheel applications, it requires new knowledge creation to combine with existing 'know-how' to be designed specifically for different uses such as in aerospace, and other transportation modes. It is believed early exploratory work is progressing with an aerospace client that is likely to evolving over several more years to refine the technology application to various transportation uses.

The dynamics of the technology for the carbon fibre wheel will vary with size and type of transport and ultimately its acceptance by global OEM customers. Recently the firm procured a contract with another European OEM car manufacturer (Ferrari) which helps consolidate the acceptance of its technology and product. Subsequently to this study's completion it was announced that this firm (Firm three – CR) has as part of its commercialisation, expansion and diversification plans to 2022 it has secured a loan to proceed with co-funding a major new research program with the University, in conjunction with the IM-CRC. This \$13m program will see the investment into this co-creation of new knowledge that consolidates their technological advances and market presence into carbon fibre wheel technology for other types of transportation.

In the case of the third SME, the data scores are lower overall across all the four AC phases. This case had the least number of respondents involved in the interviews. The firm tends to operate with a more '*closed*' innovation system by having a stronger focus on its internal capabilities and reliance on its strengths in terms of its technology platform knowledge and recruitment of highly capable staff. The firm cites it relies on less formal alliances and cooperative R&D product or process development projects with its ongoing technological development; it only relies on the University and CSIRO for specific equipment and testing capabilities, and refinement of resin materials processing. The CEO, Mr Dingle said the company regularly speaks with manufacturers that could lead to higher volume contracts on more mainstream vehicles as it expanded its manufacturing capacity and got its costs down. It is also looking at aerospace applications where weight savings are crucial. CSIRO's

materials division and Deakin's Carbon Nexus facility are helping with the development of new advanced resins – the glue in which the lightweight but very strong carbon fibres are set - and carbon fibres for future applications, including aerospace.⁴²

There is some evidence that as this firm is growing rapidly in a relatively short span it will search wider collaborative networks within its customer-supplier chain supply system, as it seeks to become an approved and recognised OEM supplier to a wider customer base, to expand its one-piece carbon fibre wheel technology into applications other than the automotive space. There is recent discussion it is in early exploratory stages with the aviation/aerospace industry, for use of its wheel technology with a range of potential aircraft. The firm's carbon fibre wheel technology could also be adopted to the aerospace industry, with specialised wheels potentially manufactured in Geelong. *"This technology has a very obvious place in the aerospace industry and that's been confirmed by a lot of international aerospace companies so that could potentially create a whole separate division of this business which will create more jobs again,"* Mr Dingle said.⁴³

Firm four has the longest gestation period; stemming from its initial novel idea in the late 1990s to patented technology in 2005 and its continuous refinement to produce faster curing times and higher-grade surface quality finishes of its carbon fibre and composite manufacturing technologies. These technologies have recently been combined to produce a 'smart factory' with greater use of automated (robotics) process to increase manufacturing capacity for large volume parts with its QPS print-to-finish process. Initially the firm sought to sell and licence its technology, as it did twice. The business strategy is now to manufacture using its technology. The continual exploration of its technology into aerospace and automotive sectors continues, and recently secured an international partnership agreement with a fellow advanced composites manufacturer in Italy. The move away from selling and licensing its technology is a potential loss of financial revenue whilst its technology has yet to secure large commercial wins.

⁴² <http://www.afr.com/business/manufacturing/geelong-firm-fits-carbon-wheels-to-600000-perfect-10-on-libidometer-ford-gt-20160517-gox7tm>

⁴³ <http://www.abc.net.au/news/2015-07-19/hi-tech-wheels-leading-geelong-s-manufacturing-revolution/6631570>

6 CHAPTER SIX: CONCLUSIONS

This case study provides evidence of a small cluster of SMEs that have emerged with assistance from R&D collaboration with Deakin University in the Greater Geelong Region. These firms value the knowledge created through its collaborations with the University that are considered an important source of external knowledge for them. This knowledge has been accessed, used and commercially exploited to drive the innovation processes of each firm through the NPD process. Specifically, the study highlights the role of a firm's AC as an important strategic business capability, critical to this success of these SMEs. The SMEs examined in this study are unique in many ways. They all had some formal and informal R&D collaboration history prior to the group contributing their own funds towards the **ARC project**. Government funding contributed towards the firms' prior collaboration experience, and the success of this experience with the university forged a shared trust that supported ongoing collaboration and inter-organisational relationships.

In the case where businesses collaborate on R&D projects with one regional university, the thesis has shown this collective learning process assists the exchange of knowledge to industry for commercial applications. These exchanges show that when SMEs and a university combined their knowledge bases through R&D collaborations both can benefit. The University has derived academic research outcomes (journal publications, conference papers, and global research partnerships with other universities and OEMs) whilst industry develop their AC in the form of product innovation outcomes. The nature of these collaborations ranges from providing material processing of various crucial raw materials required by a firm's product innovations; access and use of the university's equipment, facilities and research staff; and collaboration on short-medium term research programs. As the firms are partners to the ARC Transformation Hub research program which will deliver upon a range of outcomes to build upon the joint interests of the firms and the university.

Deakin University as a regional non-metropolitan university is contributing to a new era of university research in Australia. It is contributing to broader regional economic development efforts for a region that has experience considerable economic change. In particular the University is advancing empirical and applied investigation, to develop advances in science research, technology and engineering inventions from the incubator and laboratory scale to a 'proof of concept' scale that through additional R&D input and funding for industrial application can achieve potential commercial applications. A business can spend substantial time and resource costs (staff and money) to explore and acquire new information and knowledge. When this knowledge can be obtained, or sourced from a university, it is essential that the two parties can collaborate to achieve both organisations aspirations and interests [motivations], and the wider interests for stocks of public and private knowledge, innovation activity and its contribution to economic development (Ankrah and Al-Tabbaa, 2015).

In the case of Deakin University that represents a regional based university with a history of working with industry in the Greater Geelong area as a former heavy manufacturing-based economy it is

essential knowledge created from such facilities informs local industry and emerging new ones. Therefore a deliberate planned learning synergy must exist for technology development, university R&D and business development, support new technology-based firms. The physical co-location of the firms with the University represents opportunities to allow for the exchanges of tacit knowledge and the specific use of the capabilities of University research staff, equipment and facilities. In the case of the larger two firms where their technology advancement is reliant on the work of both the University and CSIRO research centre.

The firm's physical proximity in the Geelong Technology Precinct at Deakin University is not coincidence and was a deliberation strategy supported by the University and State and Federal Government funding. Deakin is one of few universities in Australia to have developed a research focus on manufacturing and Deakin has taken a calculated and managed risk to look at the potential for carbon fibre as an industry for the jobs of the future (Deakin University Annual Report 2013, p.21).

"Deakin University's Vice Chancellor, Jane den Hollander is extremely impressive and has a particular passion for ensuring the university and its respective institutes, including Carbon Nexus, are there to support industry and technology-based companies like us, with the sorts of outputs and services that we need to drive our businesses forward"

Research at Deakin has increased our focus on innovation and robust partnerships with industry and business. Deakin is strengthening and streamlining pathways for commercial research and commercialisation of technologies from discovery through to licensing and spin-outs, emphasising the importance of partnerships. Deakin's growing innovation program aims to attract and grow entrepreneurs by providing them with support, including training, space, equipment, Deakin knowledge and expertise. This is exemplified by our very strong relationship with Carbon Revolution, a young company making revolutionary one-piece carbon fibre wheels in a factory established on the Waurin Ponds Campus. In 2015 we have been successful in co-locating additional companies at Waurin Ponds and building research and development, and training relationships with them. Deakin's Geelong Innovation Precinct at Waurin Ponds provides an important link between technological innovation and advanced performance outcomes. (Deakin University Annual Report, 2015, p.27)

Such research capacity is essential for early product development and validation of a firm's product to achieve potential customer needs and specifications. It is imperative for SMEs to engage with a university for several reasons. The first reason pertains to the public nature of R&D investment with universities, which is largely funded by the Australian Federal Government. In fiscally tight times and in periods of economic austerity the government has sought to improve the direct research impact of universities to industry; R&D activities occurring within public universities and to assist commercial applications of new knowledge and technology. Such financial imperatives mean knowledge creation and its commercial application now must extend beyond the interests of academic researchers and the pursuit of academic scientific knowledge. This educational paradigm merges with a growing appetite for more applied practical industry usable R&D that can translate to 'accessible economic knowledge' for business and industrial to both explore and exploit for their commercial operations.

The study suggests that firms demonstrate different degrees of each of the four AC learning phases. The case study findings lean towards a blur between assimilation and transformation. In saying this, the study inductively decided based on the coded data analysis of the research participants interview responses the distribution of each firms' AC developmental pathway. The case study evidence suggests the first two SMEs pave a quicker route to realising its AC and proportional spend more of their business routines realising their AC with faster pathways to production innovations and deeper aligned collaboration activities with the University. Moreover, there is a tendency for firms to have a higher level of learning and associated business activity attributed to assimilation of acquired external without requiring substantial transformative change to their internal business routines. These firms tend to have a quicker pathway through the NPD process; are more likely to less radical or less disruptive innovations, form part of a stream of incremental advancements of a firm's product innovation pipeline - evolving from an established technology knowledge and market place/presence.

As discussed this reflects a closer collaborative relationship with the university through the NPD process that reflects the higher relational knowledge links (Schartinger, et al. (2002) in Corral de Zubielqui, et al., (2015)) universities can play within the wider innovation system. This closeness can also indicate the University's strong interest in the product outcomes of the firm derived from the specialised strengths and personal interests of research staff at the University. As such a firm's AC can be developed and enhance where its knowledge base forms a closer cognitive proximity to university research staff expertise; and that same academic has both a personal/professional interest in advancing the firm's base technology for academic credential (research papers, publications, conference papers, etc) and the outcomes of the collaborative relationship with industry forms of ongoing funded R&D research. This supports the wider interests of the University and develops deeper organisational memories. This inter-organisational dynamic scenario represents a potentially closer marrying of industry and universities intrinsic interests and extrinsic motivations as organisations.

Conversely, the last two SMEs represent firms that spend more time in the transformation phase, as a result of this tendency they seek to create a disruptive technology, with the view to substantially altering the status quo of traditional methods of designing, constructing and engineering of manufactured parts - that form integral components to the production of automotive, aerospace, other transportation modes, and all machines in general, that can benefit from using composite materials such as carbon fibre. Carbon fibre is forecasted to be increasingly used as a cost-effective construction material to well established materials, such as steel, and alloy as new manufacturing technologies develop to use composite carbon fibre materials. The current technologies used to process carbon fibre for purpose of its supply, initially as a raw material, and then in its different finished uses as a construction material for manufacturing finished parts, vary with final design requirements, purposes and different commercial applications across different industries to which carbon fibre is applied or can/potentially is applied in the future. Businesses operating in this space

rely on existing technology or seek to develop their own to which cured carbon fibre forms the material for a structure.

The last two firms discussed in this study represent businesses that heavily invest in R&D to create new technology for using carbon fibre. The fourth firm will continue to advance its technology competing with a number of other out-of-autoclave (OOA) technologies all seeking to convince global manufacturers to adopt its technology. The third firm represents an organisation that stands out with few or no other competing businesses; it represents first entry mover advantages. Some other firms have had some success with two-piece wheels, with a carbon-fibre barrel coupled to a metal hub and spokes, but these have seen problems with tolerance and durability. *“We’re the only company in the world that focuses solely on this,”* Dingle says. *“We’ve set the company up to commercialise one-piece carbon-fibre wheels and everybody comes in and works exceptionally hard all day working out better ways for doing this. We’d be naïve to think we won’t be competing at some stage, but by relentlessly driving the technology as hard as we can, we have a great opportunity to maintain the global leadership position we’ve established.”*⁴⁴

Each firm case studied in this thesis demonstrates a range of innovation capabilities across the four AC learning process that can be grouped by a number of antecedents and other considerations. AC is a complex and rewarding endeavour worthy of any business, big or small. Its success is significantly dependent on a combination of resources, procedures, processes, cognitive structures, leadership and organisational routines (Bianchi et al., 2010; Peeters, Massini and Lewin, 2014; Burcharth, Lettl and Ulhøi, 2015) that may be lacking in SMEs. AC literature infers that social interaction (Todorova and Durisin, 2007; Scuotto, Del Giudice, and Carayannis, 2017) and organisational processes (Hotho, Becker-Ritterspach and Saka-Helmhout, 2012; Dada and Fogg, 2015; Rangus and Slavec (2017) play a critical role in the development of AC.

The case study supports the view that the four dimensions of AC can be considered as parallel, as well as related to each other rather than just a discrete and linearly subsequent capacity (Todorova and Durisin, 2007). This view is echoed by Sciascia, et al., (2014) who argue that SMEs, with poor acquisition and assimilation of external knowledge, will have difficulties in successfully transforming the acquired knowledge to better address their needs. This is bound to imply some blurring and overlapping of the boundaries between assimilation and transformation as well as between other dimensions of AC (Saad, Kumar, & Bradford, 2017, p. 6919).

This thesis considers a firm's AC pathway will take predominantly one of two traditional sequences discussed by other authors that being either acquire-assimilate-exploit (AC 1 - AC 2 - AC 4) or acquire-transform-exploit (AC 1 - AC 3 - AC4). These two fundamental patterns reflect a pathway firms may take to process and utilise new external knowledge to improve business innovation

⁴⁴ https://issuu.com/amtil/docs/1286_amt_september_2015_lr., AMT Magazine, September, 2015, p.55

outcomes and performance. In addition, these two sequences can take multiple pathways to reflect several different iterative feedback loops as required for a firm to achieve its Realised AC:

- acquire-transform-acquire-assimilate-exploit;
- acquire-transform-acquire-transform-exploit;
- acquire-assimilate-transform-acquire-assimilate-exploit; or
- acquire-assimilate-transform-acquire-transform-exploit.

The 'acquire-assimilation-exploit' and/or 'transformation-exploit' pathway could be seen simply as a three-sequence AC process – as attributed by this study's evidence the firms have proportionally a third of their AC pathway developed across

- AC 1 (37 percent),
- AC 2 combined with AC 3 (34 percent), and
- AC 4 (29 percent) as shown in table 46 below.

Table 46: Study supports a three-sequence AC process

AC Stages	Firm 1 %	Firm 2 %	Firm 3 %	Firm 4 %	Total percent
AC 1 Acquire	32	33	49	42	37
AC 2 Assimilate	14	10	15	12	12
AC 3 Transform	18	28	12	21	22
	32	28	27	33	34
AC 4 Exploit	36	29	24	25	29
Potential AC	46	43	64	54	49
Realised AC	54	57	36	46	51


This simplified three step sequences could warrant further clarification; particularly in regard to the specific firm innovation activities that pertain to intra-organisational AC antecedents (Volberda, Foss, and Lyles, 2010) associated with the various internal AC innovation capabilities (Lewin, Massini and Peeters, (2011) to give greater differentiation between assimilation and transformation learning processes. This conclusion supports Todorova and Durisin (2007) encouragement of further research on transformation of knowledge structures during absorption and suggests that the drivers of transformation might differ from the drivers of assimilation.

6.1 Absorptive Capacity (AC) Model Framework

A firm's AC is a framework by which businesses such as SMEs can obtain a competitive advantage and sustain that through the lifecycle of a product by a continual renewal of its knowledge stock. When a firm seeks to acquire new knowledge to inform technological improvements to refine or create product innovations it must engage in a wide range of R&D and non-R&D innovation activities. Across these innovation activities a firm's AC can be informed by a number of organisational antecedents. These were discussed pursuant to literature (Volderba, et al., 2010) and more recent

contributors. The study identified relevant antecedents across the four learning processes of the AC identified by Zahra and George (2002). The study identified several consistent dimensions associated with each antecedent occurring across the firms between each AC learning phase – with numerous / identifiable nuances occurring within each individual firm. The study contributes to discussion about the sequence between the AC phases – as raised by Gebauer, et al (2012) and Patterson and Ambrosini (2015) to the extent that the research does not diminish Zahra and George's (2002) model, nor validate or dismiss other findings (Jansen, et al; 2005, Lane, et al, 2006, Todorova and Durisin, 2007).

Table 47: Potential Sequences of AC Phases and Identified Feedback Loops

AC Phases	Potential – <i>Exploration Innovation Learning Processes</i>		Realised – <i>Exploitation Innovation Learning Processes</i>	
	AC 1 - Acquire	AC 2 - Assimilate	AC 3 - Transform	AC 4 - Exploit
AC 1 - Acquire				
AC 2 - Assimilate				
AC 3 - Transform				
AC 4 - Exploit				
Notes			AC 1 is always the starting point for developing a firm's AC. AC represents a sequence of learning phases / steps. The sequence of phases can be followed either by down or across the table – with indicative potential feedback loops indicated that may occur in the AC process.	
	Dominant Phase		Phase represents an essential [perquisite] business routines that exists to absorb and use knowledge to achieve full utilisation of knowledge (exploited) represents a firm's Potential AC.	
Potential feedback loops	Supportive Phase (Potential feedback loops)		Phase represents additional business routines likely to be needed when existing routines have yet to absorb and use knowledge that need to be deployed to achieve a firm's Realised AC.	

The strength of each AC phase is consistent with a predominance of efforts in acquisition and exploitation phases. It was determined that this small group of SMEs are differentiated by the extent each firm has achieved its Realised AC. It was stated that the smaller two SMEs showed a sequence AC pattern of 'AC1 - AC2 - AC4' – labelled Realised AC Dominance to reflect Todorova and Durisin, 2007 AC model. Here, Realised AC dominants over Potential AC to reflect less time needed to explore to identify and acquire new knowledge and shorten timeframes for firms to achieve realisation

of its AC. This could reflect Zahra and George's (2002) efficiency ratio. The firms' exploitation learning processes and routines a higher efficiency ratio between exploring and exploitative outcomes – that is they derive product innovations quicker through the NPD process and can realise a variety of commercial applications of its innovation in form of a range of products.

The two larger SMEs followed an AC development pathway sequence similar to AC1 - AC3 - AC4' – labelled Potential AC Dominance consistent with Lane, et al., (2006) Todorova and Durisin, 2007 alternative pattern. Potential AC dominants over Realised AC to reflect the greater efforts/routines and times spent with exploring new knowledge sources. The larger two SMEs seek to develop disruptive technologies to create radical innovations to allow light weight construction materials to be applied across several industry sectors using advanced technological methods to apply carbon fibre composites. Due to the radical nature of these firm's knowledge and technology bases progress through the NPD process is much slower compared to the first two firms before they can realise a variety of commercial applications of its technology.

Furthermore, a firm's AC was analysed and presented as a process by which a business collaborates and engages with a university through phases of a typical NPD process. The extent of a firm's collaborations with the University across the NPD process can parallel a firm's AC across the two main phases of Potential and Realised AC. Few industries collaborate with universities across the full spectrum of the NPD process, those firms that do this can achieve their Realised AC sooner as shown by the first two SMEs of this study. Furthermore, the collaboration undertaken will reflect one or more of four typical types identified by Perkmann and Walsh (2009). It appears the narrower the collaboration between industry and universities in the NDP process fewer collaboration types a SME are likely to undertake with a university. As mentioned, a firm's AC appears greater when it has realised the potential of the new knowledge acquired from the university in terms of production innovation outcomes. In this instance, a firm has proceeded through the three stages of the NPD process with the university and involves at least problem solving and technology development types of collaboration with the University.

6.2 AC and NDP and Industry-University Collaborations

The nature of the businesses investigated included five SMEs that ranged from 15 to nearly 200 employees with at least ten years of formal business operations. All but one of the firms was located in the Greater Geelong region and had previously undertaken research work with University. The firms with the exception of the first firm and the engineering firm had an internal R&D capacity. Individually each firm has created and forged social (relational) relationships with the respective University staff and as a group formed a co-funding partnership with the University's ARC Transformation Hub to engage in collaborative research over a five-year period across the technology bases the alignment with the businesses and the Universities research strengths/capabilities. The case study represents a range of different industry-university collaboration types that extend three broad phases of across the NPD process. The firms' AC

develops deeper the collaboration types align with both the core business technology interests and the University's research outlook.

The firms studied formed a sample of a unique cohort of SMEs regularly engaged with R&D collaborations with Deakin University. They formed part of the Australian Research Council (ARC) Industrial Transformation Research Program (ITRP) to partly fund, with the Australian Government and Deakin University, the Futures Fibre Hub (FFH) at the University's Waurn Ponds Campus in Geelong. The success attributed to the firms' innovation performance and outcomes discussed in the thesis are predominantly the result of previous research and collaboration work prior to the inception of the FFH. The FFH funding ends in the 2021/22 financial year – there are no immediate product innovation results available to draw upon from this ARC funded R&D hub for the purpose of this study. The outcomes produced from these university-industrial R&D collaboration process are required to be reported annually to the Government, and it is too early for any output to be included in this thesis. The firms represented in this research study are high growth, profitable and successful firms/SMEs, which can contribute towards R&D funding contributions to the research work – which for the most part is not highly reflective of Australian small businesses.

6.3 The Research Questions

The study sought to answer one overriding research question and three subsequent lines of inquiry into the development of a firm's innovation capabilities through the lens of AC concept. AC provides the vehicle by which SMEs can build its innovation competency as an effective strategy to deal with a range of barriers and deficits discussed that prevails SMEs less knowledge extensive regions. The thesis gives evidence to how a firm's AC is demonstrated through a range of internal and external innovation capabilities. The research aids the study of SMEs idiosyncratic characteristics with a qualitative story of the multiple dimensions a firm's innovation capabilities, as derived from its AC, and its contribution to regional development policy and theory. Further research in this regard will contribute to regional development literatures to support a theoretical and methodological framework for the study of SMEs in these locations. Moreover, the research into highly innovative SMEs can further strengthen the case for further studies into innovation capabilities to give a stronger case to provide a 'future proofing' strategy to struggling regions in non-metropolitan Australia.

This research question has vexed many economists and when examined from a micro-economic perspective casts up business economic concepts that have evolved from the behavioural and evolutionary economic streams. The broad question harks back to classic research questions (March 1991) as to how 'exploration' and 'exploitation' should be combined. R&D companies in particular must achieve innovative new products through the acquisition of new knowledge and capabilities to ensure growth over the long-term, while at the same time, these companies must also ensure profitability in the short term by raising the level of efficiency and reliability of existing products (Kodama & Shibata, 2014, p.279). The development and role of a firm's AC as seen through the collaboration process with a university involves internal and external innovation capabilities – internal

pertains to technical/technological innovation capacity and external pertains to project innovation management capacity, particularly with its networks. These capabilities are dynamic in the sense the firm's existing capacity continuously evolve and executed through NPD process. Firms vicariously show a range of ways they capture value from external acquired knowledge through to release of a new product. Product innovations tend to evolve from R&D activities conducted internally or jointly with the University. In most cases the knowledge sought from the University reflects to a greater or lesser extent across the different firms as discussed consistent with the type of collaborations discussed by Perkmann and Walsh (2009).

6.4 Role of AC Antecedents

A firm's innovation competency viewed through the AC lens is highly subjective to a range of antecedents that gives support to dimensions across the learning processes of each phase of the concept. In the context of this research all the firms perform invariably differently across these ranges of factors. A firm's competency develops with its AC, as such there are various innovation capabilities (internal and external) that stand out from one firm to another. A firm's innovation competency stems across the full AC process that engages Potential and Realised AC stages. A firm's Potential AC infers predominantly as its operational capabilities, whilst Realised AC entails dynamic capabilities underpinned by the three core competencies of *sensing, seizing and reconfiguring* (Teece, 2007). Sensing occurs in the acquisition of knowledge phase that precedes assimilation, seizing aligns with assimilation and transformation phases that as required involve reconfiguring to exploit new knowledge. These activities form part of the firm's AC where it assimilates the acquired knowledge to fund early University commercialisation activity to collaborate further on developing an initial new product prototype for trial and testing for performance, and other characteristics.

6.5 Study Limitations and Further Research Directions

The study provided an historical recount of a firm's perspective of innovation capacity. It did give a longitudinal perspective and analysis that provided an insight into the evolution of innovation capacity and its impact on innovation performance. The study is limited by the inductive qualitative exploratory nature of the research methodology applied which can reduce the use of the results for generalisation purposes. The study attempts to give a more personal account of the role of AC to a firm's innovation performance, therefore the results are firm specific demonstrating unique idiosyncratic features through the lens of different individual participants.

The research adopted and applied an AC model and previous study (Gebauer, et al., 2012) that attributed a range of dimensions to each phase of Zahra and George's (2002) AC model. This was useful to aid coding of the interview structure. Future research could apply these AC dimensions to structured interview questions combined with a firm questionnaire survey to supplement the less structure interview questions. However, the benefit of using less structured questions allowed for the interviews to take a pathway unique to the firm whilst ensuring participants responses were kept close to the overall premise of the AC concept and its learning processes. In future research this

qualitative method could benefit from a mixed method approach with application of more sophisticated quantitative research methods of analysis.

The complex and multi-faceted character of the AC concept is confirmed by this study. The nature of learning and knowledge is complex and its relationship to organisational learning is vast. The AC concept does allow for a strategy or framework to both examine the innovation performance of a firm, and a capability by which firms can develop over time to enhance innovation outcomes through refined learning processes. It is a concept that embraces and branches into many aspects and components to business innovation and management, economic development and innovation systems theory. The ability of the AC concept that implies acquiring external knowledge, learning to know how to assimilate it into an organisation to transform a business to obtain a commercial gain or added value is at the heart of economic development and sustainable competitive business practices.

The study supports the preferred three sequences of the AC concept identified by Lane, et al., (2006) and Todorova and Durisin, (2007) and elaborated by Patterson and Ambrosini (2015) and Aribi and Dupouët (2016) to introduce the iterative feedback loops of the AC learning process. These three processes can be seen across what Zahra and George (2002) identified as Potential and Realised AC, which is founded in the exploration and exploitation learning dichotomy (March 1991) or more commonly termed as organisational ambidexterity. Embedded in this is a need for firms to be able to work across a broad network of many individuals and organisations to focus the processes of exploration and exploitative innovation learning – both driven by R&D and non-R&D based organisational activities and routines. These routines are dynamic when a firm applies them to create change when faced with business turbulence conditions, which can only be managed as good as all parts of the economic system work together.

The precursors to the success of a firm's AC within a system can be both managed and studied using a framework. This framework is supported by a raft of antecedents to a firm's innovation capability. This was explored in the study through adopting the work of Volberda, et al; (2010) and Lewin, et al., (2011) and others more recently Curado, et al., (2018); Popa, Soto-Acosta, and Martinez-Conesa (2017) Camisón, Forés, and Boronat-Navarro (2017) Enkel and Heil (2014) Roberts (2015); Belderbos, Gilsing, Lokshin, Carree, and Fernández Sastre (2018) Sandor, Jeroen, and J. (2017); Kirchberger and Pohl (2016) and Burcharth, Lettl, and Ulhøi (2015b). The merits of exploring this framework exist both in some additional insights this study provides to the AC concept. This study highlights a number of findings to provide a rich fodder of potential further research questions and areas of investigation pertaining to SMEs.

Consistent with others, the strong themes emerging from an AC study are numerous. The inherent nature of the AC infers need from strong personal or 'soft skills' pertaining to working with a variety of external partners to an organisation. Similarly, internally to an organisation a similar sense of

working broadly amongst a coordinated internal network is critical to an organisation, particularly the prior experience, knowledge, skills and training that people initially bring to a place but the ongoing cognitive learning and development of individuals. Learning is an individual process to a person and it is also a social process. Firms that encourage an external outward looking culture will be exposed to changes, some seen and some unforeseen. When firm sources external knowledge from a diverse group of partners' strong social networks can develop and this can build relationships that can be galvanised to manage change.

Where firms rely on one or a few sources of external knowledge or a particularly familiar knowledge exchange pattern this can lead to a path dependency situation. From the industry-university collaboration perspective, the source of knowledge acquired from a university can be enormous, overwhelming and sometimes dissimilar to an existing organisation's knowledge that makes it difficult to absorb and or apply. This study of a small group of SMEs with a knowledge foundation built upon by either strong business experience, entrepreneurial sense of discovery, and/or intellectual prowess when firms are open to working with a university; they clearly see the benefits and continue to work with this sector. The benefits from the different types of industry-university collaborations has been explored by many (Ankrah & Al-Tabbaa, 2015; Bhullar, Nangia, & Batish, 2017; Brettel & Cleven, 2011; Buganza, Colombo, & Paolo, 2014; Perkmann & Walsh, 2009; Rajalo & Vadi, 2017; Skute, Zalewska-Kurek, Hatak, & de Weerd-Nederhof, 2017).

Recently Galati and Bigliardi (2017) provided an improved understanding of the NPD process and the type of knowledge networks and partners firms engage with; underlined by three theoretical perspectives:

- transaction cost theory (David and Han 2004; Bigliardi and Galati 2016),
- social network theory (Ireland, Hitt, and Vaidyanath 2002), and
- inter-organisational learning (Inkpen and Tsang 2005; Bigliardi, et al., 2012).

The first stresses the benefits for firms engaging in networks, resulting in a transactions costs reduction, but with the need to minimise partners' opportunistic behaviour. The second addresses the different ties related to NPD and partners' characteristics in order to highlight beneficial networks forms. The third examines how firms gain organisational capabilities from their NPD networks. A deeper understanding of how firms select their NPD partners is gaining growing interest in the current debate, due to the importance of the impact of these decisions on firms' performance and competitiveness (Knudsen and Mortensen 2011), and the shift from common R&D partnerships to more open joint R&D projects (Galati and Bigliardi 2016) as part of an open innovation system (Chesbrough, 2003).

Some firms are inherently embedded with advanced technology knowledge bases as such it makes good business sense/logic to work on refining its own technology or developing new technology with a university. For smaller firms with a product innovation they have developed [or are developing] when a connection with the right researcher and university that has an expertise and strength that is

related or not too dissimilar to the firms then a potential partnership can be explored between the two parties. This was the experience of the first two firms in this study and both have benefited from social relationships between the organisation and the University in terms of trust, partnering and technological familiarity. In this way, the two parties develop their collaborative relationship step-by-step, learning to know and trust each other, increasing the likelihood of a successful collaboration. This theme is consistent with the findings of many others such as Buganza, et al., (2014), Muscio and Vallanti (2014) and Muscio (2007).

The study confirms that firms with a well-developed AC can sustain and benefit from collaborations with a university, moreover if the firm engages with more extensive collaborations types that are related to the firm's core knowledge and technology platform and the university's areas of research expertise and academic interests. Firms that have a greater alignment with the University researchers tend to deal with novel innovations that are new to the firm's market. Whilst not radical innovations in terms of new-to-world novelty value these firms proceed through the NPD process more closely with the University and engage in two or more collaboration types. This was the case of the first two smaller firms in this study that take a quicker pathway to achieve Realised AC and commercial outcomes. In the case of the first SME it was introduced to the University through a formal government enterprise connection program to assist introduce firms with no prior experience of working with researchers. This is a common barrier for many SMEs, as firms with no experience with industry-university collaborations are more common than larger firms.

Industry-university collaboration is not a one-way process whereby industry adopts technology and knowledge provided by universities. Instead, industry must play a major role in innovation by providing its own development resources, based on university technologies. Therefore, 'experience' matters with joint R&D with universities. Naturally, established large firms are likely to have more experience than smaller firms, particularly new technology-based firms. In the case of smaller firms it has been identified that the roles and responsibilities of each party in undertaking the collaboration can be unclear. When it comes to contractual management issues a small firm can overcome incomplete contract problems, because a person who is responsible for the collaboration decision generally negotiates directly with university professors. Large firms with bureaucratic organisational structures require clearer contracts to advance the internal decision-making process (Motohashi, 2005).

The two larger SMEs explored in this study are less connected or wedded to the University, explore higher novelty innovations that are radical or more disruptive in nature. This generally involves more uncertainty, higher risk and longer timeframes to develop its technology advances and achieve commercial returns from it. In time the technology platforms of these two firms will develop through additional collective learning alliances. This will involve their specific technology and knowledge disciplines combining with the expertise of the University and other external partners. This is beginning to occur for the third firm with a recent announcement of a \$15 million funded major

commercialisation research program between the firm, the University and the IM-CRC. With respect to the fourth firm, its technology has developed over a number of recent years with internal improvements to the firm's capabilities. It continues to explore commercial opportunities using its technology and the University assists this with a number of smaller product demonstration projects within the European OEM automotive sector.

Further research into how to support SMEs engage with universities in NDP processes is warranted. This is underpinned by firms developing their AC as an overall innovation capability as one of many core competencies forming part a business strategic innovation plan. The study's exploration of these smaller firms demonstrated how AC relates to the NPD process and the basic types of industry-university collaborations types and the nature of different activities they undertake together. To successfully manage the NDP process firms need AC across this theme that relates to innovation capabilities. More specifically, technology management capabilities that allow firms to reduce the cost and risk associated with correctly defining their needs (access costs) and assessing the results (interface costs). However, project management capabilities allow firms to manage the relationship (interface costs) with industrial standards, considering dimensions such as time and cost and thus increasing the chances of a successful collaboration. As shown in this research the SMEs demonstrate capabilities in both of these two broad categories. This assessment was made in chapter five, based on the idiosyncratic AC findings for each firm in chapter four.

It would seem, both technological management in conjunction with project management capabilities, are essential for a firm's AC and innovation performance and outcomes. Future research studies could examine more closely which AC learning processes and their underlying antecedents support each of these two-broad types of capabilities and specifically the extent to which they pertain to internal and/or external capabilities that form meta-routines (Lewin, et al., 2011) to firms. Previous research (Buganza, et al., 2014) showed that SMEs engaging in collaborations during the research phase display greater capabilities in both areas, however firms with no prior experience when initially engaging with universities in more basic academic assisted collaborations to gain experience and confidence in their own abilities to develop partnering skills and trust relationships with individual university researchers. This has recently been explored in detail by Bhullar, Nangia and Batish (2017) for emerging newly developed countries such as India.

Summary of SMEs Innovation Capability					
Firm	SMEs Innovation Capability				
	Technology Management	Project Management	NPD Process - Phases Taken		
	Capability Level	Capability Level	Applied R&D	Proof Concept 'Testing & Validation'	Industrial Commercial
1	Medium	Medium-High	√	√	√
2	High	High	—	√	√
3	High	Medium-High	—	√	—
4	Medium-High	Medium	—	√	√
√	Evidence				
—	No evidence				

Bhullar, et al., (2017) study deals with the engagement of academics with the industry using different channels for the transfer of knowledge and technology. The study provides empirical evidence substantiating the effect of the frequency of use of the different channels of interaction in explaining the relationship between past collaborative experience of the academic and the outcomes of academia–industry collaboration. The results indicate that past collaborative experience develops strong insights into industrial problems, opens up avenues for research projects, leads to industrial funding and builds research networks. The prospects of commercialisation of research of the academic are also rooted in past collaborative experience. The results also reveal that the frequency of use of the traditional and bi-directional channels partially mediate the relationship between the collaborative experience and the outcomes of collaboration – validating that higher collaborative experience leads to increased frequency of use of channels that results in improved outcomes of industry-university collaboration (Bhullar, et al., (2017)).

The case study presented examples of SMEs that have developed their AC with a variety of innovation capabilities to sufficiently show it has a significant positive effect on SMEs innovation outcomes. Unlike other studies (Corral de Zubielqui, et al., (2015) and Jones and Corral de Zubielqui, (2017)) this case study provides sufficient evidence to indicate that SMEs through their AC have established broader knowledge-based linkages with Universities across a number of different collaborative research partnerships and services to have an effect on its innovation outcomes. Furthermore, many of the SMEs in this study rely on the University for both generic and higher relational knowledge links. This study also contributes to a greater understanding to how SMEs

develop their AC to support strategies that seek a clear distinction between generic and relational university-interactions. Whilst generic university-firm links, in particular human resource transfers, are the predominant mechanism that is said to promote innovation outcomes at the firm level, further studies are needed to support deeper engagement between SMEs with higher relational knowledge exchanges with universities.

This study would support the findings of Corral de Zubielqui, et al., (2015) and Jones and Corral de Zubielqui, (2017) to encourage more efforts to nurture industry-university collaborations that promote relational knowledge links such as research partnerships and services. As discussed, quantitative studies of SMEs have been shown that most SMEs do not use universities as their preferred source of external knowledge. When the few SMEs that do engage with scientific partners such as universities beyond the generic knowledge links, they appear to have a positive effect on innovation outcomes. This is on the condition that future knowledge exchanges are mediated through a firm's AC (Corral de Zubielqui, et al., 2016). As highlighted by Jones and Corral de Zubielqui (2017, p.268) with SMEs possessing sufficient AC industry-university collaborations could tentatively suggest that they have little utility. This study supports calls for further longitudinal research needed first to test a firm's AC and use of universities higher relational knowledge accessed through research collaborations and learning partnerships in order to determine whether there is a lag effect between implementation and effect and a firm's innovation capacity to explore and exploit such knowledge links with universities (Jones and Corral de Zubielqui 2017, p.268).

Future similar research can be enhanced and extended to focus on larger and more diversified contexts such as different industries and adopt the ten-innovation capacity (IC) dimensions presented by Pierre and Fernandez (2018, pp.164-165). Extensions through quantitative methods such as large surveys on representative samples would assist analysing multiple relationships around SMEs' innovation capacity. For example, future research could assess the importance of each dimension of innovation capacity in order to highlight the most important ones. This study did discuss the influence that AC had on the innovation capacity in terms of innovation type (product, process, etc.) and degree (incremental or radical) that is suggested by Pierre and Fernandez (2018, p.170). The study's findings give a future methodology to the study of SMEs' innovation capacity based on the learning process of a firm's AC, examined from the perspective of a broad NDP process in context of different industry-university collaboration types.

From this study emerged two different types of AC:

- (i) one group of smaller SMEs have the propensity to develop their Realised AC quickly, which followed the AC 1 - AC 2 - AC 4 learning process sequence; and
- (ii) a second group of larger SMEs that are slower to achieve Realised AC, which followed the AC 1 - AC 3 - AC 4 learning process sequence.

The difference between these two groups of SMEs can be attributed to the level of innovation novelty value (incremental 'new to a firm's market' versus radical disruptive 'new to world market')

innovations); and ultimately a firm's ability to use their AC through the NDP process across a number of different industry-university collaboration types. This study would support further similar research that adopted the framework of innovation capacities (IC) devised by Pierre and Fernandez (2018) to help measure the relationship between AC and these IC dimensions' influence and their impact on SMEs' innovation performance. This could be achieved by performing multiple statistical tests to investigate and go deeper regarding which dimensions are crucial or minor. Such future studies would help measure cross effects between the ten dimensions of SMEs' innovation capacity and AC.

As suggested by Pierre and Fernandez (2018, p.168) based on their results it showed that several dimensions have a major impact on others and highlight the need to further investigate this type of relation to fully understand SMEs' innovation capacity foundations. For example, Business owner/entrepreneur characteristics:

- (i) Personal expertise: *technical specialisation; market knowledge and business development abilities; personal network; and*
- (ii) Personality: *openness; risk taking; communication on vision and objectives - clearly influence network integration, strategy and conditions for innovation.*

Such an approach would provide a good framework for advancing heterogeneity debates. By integrating moderating variables, such as age and size, discussed by the literature as determinant context factors for innovation (Saunila, 2016 and 2014; Phelps, et al., 2007), innovation type (Garcia, Calantone, 2002), industry (Forsman, 2011) and sectorial activity (De Jong, Marsili, 2006), would enhance future AC study methodologies (Pierre and Fernandez, 2018, p.169). This would also provide a framework to give more precision to the specifics of SMEs AC to advance empirical evidence and elaborate on further debates to the usefulness of the AC theory to a firm's innovation capacity.

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